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THE INSTITUTION

OF

MECHANICAL ENGINEERS.

ESTABLISHED 1847.

PROCEEDINGS.

48322 / 1900

1899.

PARTS 1–2.

PUBLISHED BY THE INSTITUTION,

STOREY'S' GATE, ST. JAMES'S PARK, WESTMINSTER, S.W.

CONTENTS.

1899.

PARTS 1–2.

PAST-PRESIDENTS.

George Stephenson, 1847–48. (*Deceased* 1848.)

Robert Stephenson, F.R.S., 1849–53. (*Deceased* 1859.)

Sir William Fairbairn, Bart., LL.D., F.R.S., 1854–55. (*Deceased* 1874.)

Sir Joseph Whitworth, Bart., D.C.L., LL.D., F.R.S., 1856–57, 1866. (*Deceased* 1887.)

John Penn, F.R.S., 1858–59, 1867–68. (*Deceased* 1878.)

James Kennedy, 1860. (*Deceased* 1886.)

The Right Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S., 1861-62, 1869.

Robert Napier, 1863–65. (*Deceased* 1876.)

John Ramsbottom, 1870–71. (*Deceased* 1897.)

Sir William Siemens, D.C.L., LL.D., F.R.S., 1872–73. (*Deceased* 1883.)

Sir Frederick J. Bramwell, Bart., D.C.L., LL.D., F.R.S., 1874–75.

Thomas Hawksley, F.R.S., 1876–77. (*Deceased* 1893.)

John Robinson, 1878–79.

Edward A. Cowper, 1880–81. (*Deceased* 1893.)

Percy G. B. Westmacott, 1882–83.

Sir Lowthian Bell, Bart., F.R.S., 1884.

Jeremiah Head, 1885–86. (*Deceased* 1899.)

Sir Edward H. Carbutt, Bart., 1887–88.

Charles Cochrane, 1889. (*Deceased* 1898.)

Joseph Tomlinson, 1890–91. (*Deceased* 1894.)

Sir William Anderson, K.C.B., D.C.L., F.R.S., 1892–93. (*Deceased* 1898.)

Alexander B. W. Kennedy, LL.D., F.R.S., 1894–95.

E. Windsor Richards, 1896–97.

Samuel Waite Johnson, 1898.

The Institution of Mechanical Engineers.

OFFICERS.

1899.

PRESIDENT.

Sir William H. White, K.C.B., LL.D., D.Sc., F.R.S., .. London.

PAST-PRESIDENTS.

The Rt. Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S., Newcastle-on-Tyne.
Sir Lowthian Bell, Bart., F.R.S., ... Northallerton.
Sir Frederick J. Bramwell, Bart., D.C.L., LL.D., F.R.S., London.
Sir Edward H. Carbutt, Bart., ... London.
Jeremiah Head (*deceased March*, 1899), ... London.
Samuel Waite Johnson, ... Derby.
Alexander B. W. Kennedy, LL.D., F.R.S., ... London.
E. Windsor Richards, ... Caerleon.
John Robinson, ... Leek.
Percy G. B. Westmacott, ... Ascot.

VICE-PRESIDENTS.

Sir Douglas Galton, K.C.B., F.R.S., (*deceased March*, 1899) London.
Arthur Keen, ... Birmingham.
Edward P. Martin, ... Dowlais.
William H. Maw, ... London.
T. Hurry Riches, ... Cardiff.
A. Tannett Walker, ... Leeds.
J. Hartley Wicksteed, ... Leeds.

MEMBERS OF COUNCIL.

Sir William Arrol, M.P., LL.D., ... Glasgow.
John A. F. Aspinall, ... Horwich.
Sir Benjamin Baker, K.C.M.G., LL.D., F.R.S., ... London.
Henry Chapman, ... London.
Henry Davey, ... London.
William Dean, ... Swindon.
Bryan Donkin, ... London.
Edward B. Ellington, ... London.
H. Graham Harris, ... London.
Henry Lea, ... Birmingham.
John G. Mair-Rumley, ... London.
Henry D. Marshall, ... Gainsborough.
The Right Hon. William J. Pirrie, ... Belfast.
Sir Thomas Richardson, M.P., ... Hartlepool.
John I. Thornycroft, F.R.S., ... London.

TREASURER.

Harry Lee Millar.

SECRETARY.

Edgar Worthington,

The Institution of Mechanical Engineers, Storey's Gate, St. James's Park, Westminster, S.W.

Telegraphic address:—*Mech, London.* Telephone:—*Westminster*, 264.

THE INSTITUTION OF MECHANICAL ENGINEERS.

Memorandum of Association.

AUGUST 1878.

1st. The name of the Association is "THE INSTITUTION OF MECHANICAL ENGINEERS."

2nd. The Registered Office of the Association will be situate in England.

3rd. The objects for which the Association is established are:—

(A.) To promote the science and practice of Mechanical Engineering and all branches of mechanical construction, and to give an impulse to inventions likely to be useful to the Members of the Institution and to the community at large.

(B.) To enable Mechanical Engineers to meet and to correspond, and to facilitate the interchange of ideas respecting improvements in the various branches of mechanical science, and the publication and communication of information on such subjects.

(C.) To acquire and dispose of property for the purposes aforesaid.

(D.) To do all other things incidental or conducive to the attainment of the above objects or any of them.

4th. The income and property of the Association, from whatever source derived, shall be applied solely towards the promotion of the objects of the Association as set forth in this Memorandum of Association, and no portion thereof shall be paid or transferred directly or indirectly, by way of dividend, bonus, or otherwise howsoever, by way of profit to the persons who at any time are or have been Members of the Association, or to any of them, or to any person claiming through any of them: Provided that nothing herein contained shall prevent the payment in good faith of remuneration to any officers or servants of the Association, or to any Member of the Association, or other person, in return for any services rendered to the Association, or prevent the giving of privileges to the Members of the Association in attending the meetings of the Association, or prevent the borrowing of money (under such powers as the Association and the Council thereof may possess) from any Member of the Association, at a rate of interest not greater than five per cent. per annum.

5th. The fourth paragraph of this Memorandum is a condition on which a licence is granted by the Board of Trade to the Association in pursuance of Section 23 of the Companies Act 1867. For the purpose of preventing any evasion of the terms of the said fourth paragraph, the Board of Trade may from time to time, on the application of any Member of the Association, impose further conditions, which shall be duly observed by the Association.

6th. If the Association act in contravention of the fourth paragraph of this Memorandum, or of any such further conditions, the liability of every Member of the Council shall be unlimited; and the liability of every Member of the Association who has received any such dividend, bonus, or other profit as aforesaid, shall likewise be unlimited.

7th. Every Member of the Association undertakes to contribute to the Assets of the Association in the event of the same being wound up during the time that he is a Member, or within one

year afterwards, for payment of the debts and liabilities of the Association contracted before the time at which he ceases to be a Member, and of the costs, charges, and expenses for winding up the same, and for the adjustment of the rights of the contributories amongst themselves, such amount as may be required not exceeding Five Shillings, or in case of his liability becoming unlimited such other amount as may be required in pursuance of the last preceding paragraph of this Memorandum.

8th. If upon the winding up or dissolution of the Association there remains, after the satisfaction of all its debts and liabilities, any property whatsoever, the same shall not be paid to or distributed among the Members of the Association, but shall be given or transferred to some other Institution or Institutions having objects similar to the objects of the Association, to be determined by the Members of the Association at or before the time of dissolution; or in default thereof, by such Judge of the High Court of Justice as may have or acquire jurisdiction in the matter.

Articles of Association.

February 1893.

INTRODUCTION.

Whereas an Association called "The Institution of Mechanical Engineers" existed from 1847 to 1878 for objects similar to the objects expressed in the Memorandum of Association of the Association (hereinafter called "the Institution") to which these Articles apply;

And whereas the Institution was formed in 1878 for furthering and extending the objects of the former Institution, by a registered Association, under the Companies Acts 1862 and 1867;

And whereas terms used in these Articles are intended to have the same respective meanings as they have when used in those Acts, and words implying the singular number are intended to include the plural number, and *vice versâ*;

Now therefore it is hereby agreed as follows :—

CONSTITUTION.

1. For the purpose of registration the number of members of the Institution is unlimited.

MEMBERS, ASSOCIATE MEMBERS, GRADUATES, ASSOCIATES, AND HONORARY LIFE MEMBERS.

2. The present Members of the Institution, and such other persons as shall be admitted in accordance with these Articles, and none others, shall be Members of the Institution, and be entered on the register as such.

3. Any person may become a Member of the Institution who shall be qualified and elected as hereinafter mentioned, and shall agree to become such Member, and shall pay the entrance fee and first subscription accordingly.

4. The qualification of Members shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

5. The election of Members shall be conducted as prescribed by the By-laws from time to time in force, as provided by the Articles.

6. In addition to the persons already admitted as Graduates, Associates, and Honorary Life Members respectively, the Institution may admit such persons as may be qualified and elected in that behalf as Associate Members, Graduates, Associates, and Honorary Life Members respectively of the Institution, and may confer upon them such privileges as shall be prescribed by the By-laws from time to time in force, as provided by the Articles: provided that no Associate Member, Graduate, Associate, or Honorary Life Member shall be deemed to be a Member within the meaning of the Articles.

7. The qualification and mode of election of Associate Members, Graduates, Associates, and Honorary Life Members shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

8. The rights and privileges of every Member, Associate Member, Graduate, Associate, or Honorary Life Member shall be personal to himself, and shall not be transferable or transmissible by his own act or by operation of law.

ENTRANCE FEES AND SUBSCRIPTIONS.

9. The Entrance Fees and Subscriptions of Members, Associate Members, Graduates, and Associates shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

EXPULSION.

10. If any Member, Associate Member, Graduate, or Associate shall leave his subscription in arrear for two years, and shall fail to pay such arrears within three months after a written application has been sent to him by the Secretary, his name may be struck off the register by the Council at any time afterwards, and he shall thereupon cease to have any rights as a Member, Associate Member, Graduate, or Associate, but he shall nevertheless continue liable to pay the arrears of subscription due at the time of his name being so struck off: provided always that this regulation shall not be construed to compel the Council to remove any name, if they shall be satisfied the same ought to be retained.

11. The Council may refuse to continue to receive the subscriptions of any person who shall have wilfully acted in contravention of the regulations of the Institution, or who shall in the opinion of the Council have been guilty of such conduct as shall have rendered him unfit to continue to belong to the Institution; and may remove his name from the register, and he shall thereupon cease to be a Member, Associate Member, Graduate, or Associate (as the case may be) of the Institution.

GENERAL MEETINGS.

12. The General Meetings shall consist of the Ordinary Meetings, the Annual General Meeting, and of Special Meetings as hereinafter defined.

13. The Annual General Meeting shall take place in London in one of the first four months of every year. The Ordinary Meetings shall take place at such times and places as the Council shall determine.

14. A Special Meeting may be convened at any time by the Council, and shall be convened by them whenever a requisition signed by twenty Members or Associate Members of the Institution,

specifying the object of the Meeting, is left with the Secretary. If for fourteen days after the delivery of such requisition a Meeting be not convened in accordance therewith, the Requisitionists or any twenty Members or Associate Members of the Institution may convene a Special Meeting in accordance with the requisition. All Special Meetings shall be held in London.

15. Seven clear days' notice of every Meeting, specifying generally the nature of any special business to be transacted at any Meeting, shall be given to every person on the register of the Institution, except as provided by Article 35, and no other special business shall be transacted at such Meeting; but the non-receipt of such notice shall not invalidate the proceedings of such Meeting. No notice of the business to be transacted (other than such ballot lists as may be requisite in case of elections) shall be required in the absence of special business.

16. Special business shall include all business for transaction at a Special Meeting, and all business for transaction at every other Meeting, with the exception of the reading and confirmation of the Minutes of the previous Meeting, the election of Members, Associate Members, Graduates, and Associates, and the reading and discussion of communications as prescribed by the By-laws, or by any regulations of the Council made in accordance with the By-laws.

PROCEEDINGS AT GENERAL MEETINGS.

17. Twenty Members or Associate Members shall constitute a quorum for the purpose of a Meeting other than a Special Meeting. Thirty Members or Associate Members shall constitute a quorum for the purpose of a Special Meeting.

18. If within thirty minutes after the time fixed for holding the Meeting a quorum is not present, the Meeting shall be dissolved, and all matters which might, if a quorum had been present, have been done at a Meeting (other than a Special Meeting) so dissolved, may forthwith be done on behalf of the Meeting by the Council.

19. The President shall be Chairman at every Meeting, and in his absence one of the Vice-Presidents; and in the absence of all Vice-Presidents a Member of Council shall take the chair; and if no Member of Council be present and willing to take the chair, the Meeting shall elect a Chairman.

20. The decision of a General Meeting shall be ascertained by show of hands, unless, after the show of hands, a poll is forthwith demanded; and by a poll, when a poll is thus demanded. The manner of taking a show of hands or a poll shall be in the discretion of the Chairman; and an entry in the Minutes, signed by the Chairman, shall be sufficient evidence of the decision of the General Meeting. Each Member and Associate Member shall have one vote and no more. In case of equality of votes the Chairman shall have a second or casting vote: provided that this Article shall not interfere with the provisions of the By-laws as to election by ballot.

21. The acceptance or rejection of votes by the Chairman shall be conclusive for the purpose of the decision of the matter in respect of which the votes are tendered: provided that the Chairman may review his decision at the same Meeting, if any error be then pointed out to him.

BY-LAWS.

22. The By-laws set forth in the schedule to these Articles, and such altered and additional By-laws as shall be substituted or added as hereinafter mentioned, shall regulate all matters by the Articles left to be prescribed by the By-laws, and all matters which consistently with the Articles shall be made the subject of By-laws. Alterations in, and additions to, the By-laws, may be made only by resolution of the Members and Associate Members at an Annual General Meeting, after notice of the proposed alteration or addition has been announced at the previous Ordinary Meeting, and not otherwise.

COUNCIL.

23. The Council of the Institution shall be chosen from the Members only, and shall consist of one President, six Vice-Presidents, fifteen ordinary Members of Council, and of the Past-Presidents. The President, two Vice-Presidents, and five Members of Council (other than Past-Presidents), shall retire at each Annual General Meeting, but shall be eligible for re-election. The Vice-Presidents and Members of Council to retire each year shall, unless the Council agree among themselves, be chosen from those who have been longest in office, and in cases of equal seniority shall be determined by ballot.

24. The election of a President, Vice-Presidents, and Members of Council, to supply the place of those retiring at the Annual General Meeting, shall be conducted in such manner as shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

25. The Council may supply any casual vacancy in the Council (including any casual vacancy in the office of President) which shall occur between one Annual General Meeting and another; and the President, Vice-Presidents, or Members of Council so appointed by the Council shall retire at the succeeding Annual General Meeting. Vacancies not filled up at any such Meeting shall be deemed to be casual vacancies within the meaning of this Article.

OFFICERS.

26. The Treasurer, Secretary, and other employés of the Institution shall be appointed and removed in the manner prescribed by the By-laws from time to time in force, as provided by the Articles. Subject to the express provisions of the By-laws, the officers and servants of the Institution shall be appointed and removed by the Council.

27. The powers and duties of the officers of the Institution shall, subject to any express provision in the By-laws, be determined by the Council.

POWERS AND PROCEDURE OF COUNCIL.

28. The Council may regulate their own procedure, and delegate any of their powers and discretions to any one or more of their body, and may determine their own quorum: if no other number is prescribed, three members of Council shall form a quorum.

29. The Council shall manage the property, proceedings, and affairs of the Institution, in accordance with the By-laws from time to time in force.

30. The Treasurer may, with the consent of the Council, invest in the name of the Institution any moneys not immediately required for the purposes of the Institution in or upon any of the following investments (that is to say):—

(A) The Public Funds, or Government Stocks of the United Kingdom, or of any Foreign or Colonial Government guaranteed by the Government of the United Kingdom.

(B) Real or Leasehold Securities, or in the purchase of real or leasehold properties in Great Britain or Ireland.

(C) Debentures, Debenture Stock, or Guaranteed or Preference Stock, of any Company incorporated by special Act of Parliament, the ordinary Shareholders whereof shall at the time of such investment be in actual receipt of half-yearly or yearly dividends.

(D) Stocks, Shares, Debentures, or Debenture Stock of any Railway, Canal, or other Company, the undertaking whereof is leased to any Railway Company at a fixed or fixed minimum rent.

(E) Stocks, Shares, or Debentures of any East Indian Railway or other Company, which shall receive a contribution from Her Majesty's East Indian Government of a fixed annual percentage on their capital, or be guaranteed a fixed annual dividend by the same Government.

(F) The security of rates levied by any corporate body empowered to borrow money on the security of rates, where such borrowing has been duly authorised by Act of Parliament.

31. The Council may, with the authority of a resolution of the Members and Associate Members in General Meeting, borrow moneys for the purposes of the Institution on the security of the property of the Institution, or otherwise at their discretion.

32. No act done by the Council, whether *ultra vires* or not, which shall receive the express or implied sanction of the Members and Associate Members in General Meeting, shall be afterwards impeached by any member of the Institution on any ground whatsoever, but shall be deemed to be an act of the Institution.

NOTICES.

33. A notice may be served by the Council upon any Member, Associate Member, Graduate, Associate, or Honorary Life Member, either personally or by sending it through the post in a prepaid letter addressed to him at his registered place of abode.

34. Any notice, if served by post, shall be deemed to have been served at the time when the letter containing the same would be delivered in the ordinary course of the post; and in proving such service it shall be sufficient to prove that the letter containing the notice was properly addressed and put into the post office.

35. No Member, Associate Member, Graduate, Associate, or Honorary Life Member, not having a registered address within the United Kingdom, shall be entitled to any notice; and all proceedings may be had and taken without notice to such member, in the same manner as if he had had due notice.

By-laws.

(*Last Revision, February* 1894.)

MEMBERSHIP.

1. Candidates for admission as Members must be persons not under twenty-five years of age, who, having occupied during a sufficient period a responsible position in connection with the practice or science of Engineering, may be considered by the Council to be qualified for election.

2. Candidates for admission as Associate Members must be persons not under twenty-five years of age, who, being engaged in such work as is connected with the practice or science of Engineering, may be considered by the Council to be qualified for election, though not yet to occupy positions of sufficient responsibility, or otherwise not yet to be eligible, for admission as Members. They may afterwards be transferred at the discretion of the Council to the class of Members.

3. Candidates for admission as Graduates must be persons holding subordinate situations, and not under eighteen years of age. They must furnish evidence of training in the principles as well as in the practice of Engineering. Before attaining the age of twenty-six years, those elected after 1892 must apply for election as Members, Associate Members, or Associates, if they desire to remain connected with the Institution; they may not continue Graduates after attaining the age of twenty-six.

4. Candidates for admission as Associates must be persons not under twenty-five years of age, who from their scientific attainments or position in society may be considered eligible by the Council. They may afterwards be transferred at the discretion of the Council to the class of Associate Members or of Members.

5. The Council shall have the power to nominate as Honorary Life Members persons of eminent scientific acquirements, who in their opinion are eligible for that position.

6. The Members, Associate Members, Graduates, Associates, and Honorary Life Members shall have notice of and the privilege to attend all Meetings; but Members and Associate Members only shall be entitled to vote thereat.

7. The abbreviated distinctive Titles for indicating the connection with the Institution of Members, Associate Members, Graduates, Associates, or Honorary Life Members thereof, shall be the following:—for Members, M. I. Mech. E.; for Associate Members, A. M. I. Mech. E.; for Graduates, G. I. Mech. E.; for Associates, A. I. Mech. E.; for Honorary Life Members, Hon. M. I. Mech. E.

8. Subject to such regulations as the Council may from time to time prescribe, any Member, Associate Member, or Associate may upon application to the Secretary obtain a Certificate of his membership or other connection with the Institution. Every such certificate shall remain the property of, and shall on demand be returned to, the Institution.

ENTRANCE FEES AND SUBSCRIPTIONS.

9. Each Member shall pay an Annual Subscription of £3, and on election an Entrance Fee of £2.

10. Each Associate Member shall pay an Annual Subscription of £2 10*s.*, and on election an Entrance Fee of £1. If afterwards transferred by the Council to the class of Members, he shall pay on transference 10*s.* additional subscription for the current year, and £1 additional entrance fee.

11. Each Graduate shall pay an Annual Subscription of £1 10*s.*, but no Entrance Fee. Any Graduate elected prior to 1893, if transferred by the Council to the class of Associate Members, shall pay on transference £1 additional subscription for the current year, but no additional entrance fee; if transferred direct to the class of Members, he shall pay on transference £1 10*s.* additional subscription for the current year, and £1 additional entrance fee.

12. Each Associate shall pay an Annual Subscription of £2 10*s.*, and on election an Entrance Fee of £1. If afterwards transferred by the Council to the class of Associate Members, he shall pay on transference no additional subscription or entrance fee. If transferred direct to the class of Members, he shall pay on transference 10*s.* additional subscription for the current year, and £1 additional entrance fee; except Associates elected prior to 1893, who shall pay no additional entrance fee on transference.

13. All subscriptions shall be payable in advance, and shall become due on the 1st day of January in each year; and the first subscription of Members, Associate Members, Graduates, and Associates, shall date from the 1st day of January in the year of their election.

14. In the case of Members, Associate Members, Graduates, or Associates, elected in the last three months of any year, the first subscription shall cover both the year of election and the succeeding year.

15. Any Member, Associate Member, or Associate, whose subscription is not in arrear, may at any time compound for his subscription for the current and all future years by the payment of Fifty Pounds, if paid in any one of the first five years of his membership. If paid subsequently, the sum of Fifty Pounds shall be reduced by One Pound per annum for every year of membership after five years. All compositions shall be deemed to be capital moneys of the Institution.

16. The Council may at their discretion reduce or remit the annual subscription, or the arrears of annual subscription, of any Member or Associate Member who shall have been a subscribing member of the Institution for twenty years, and shall have become unable to continue the annual subscription provided by these By-laws.

17. No Proceedings or Ballot Lists or Certificates shall be sent to Members, Associate Members, Graduates, or Associates, who are in

arrear with their subscriptions more than twelve months, and whose subscriptions have not been remitted by the Council as hereinbefore provided.

ELECTION OF MEMBERS, ASSOCIATE MEMBERS, GRADUATES, AND ASSOCIATES.

18. A recommendation for admission according to Form A or B in the Appendix shall be forwarded to the Secretary, and by him be laid before the next Meeting of the Council. The recommendation must be signed by not less than five Members or Associate Members if the application be for admission as a Member or Associate Member or Associate, and by three Members or Associate Members if it be for a Graduate.

19. All elections shall take place by ballot, four-fifths of the votes given being necessary for election.

20. All applications for admission shall be communicated by the Secretary to the Council for their approval previous to being inserted in the ballot list for election, and the approved ballot list shall be signed by the President and forwarded to the Members and Associate Members. The name of any Candidate approved by the Council for admission as an Associate Member or an Associate shall not be inserted in the ballot list until he has signed the Form C in the Appendix. The ballot list shall specify the name, occupation, and address of the Candidates, and also by whom proposed and seconded. The lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

21. The Elections shall take place at the General Meetings only.

22. When the proposed Candidate is elected, the Secretary shall give him notice thereof according to Form D; but his name shall not be added to the register of the Institution until he shall have paid his Entrance Fee and first Annual Subscription, and signed the Form E in the Appendix.

23. In case of non-election, no mention thereof shall be made in the Minutes, nor any notice given to the unsuccessful Candidate.

24. An Associate Member desirous of being transferred to the class of Members, or an Associate to the class of Associate Members or of Members, shall forward to the Secretary a recommendation according to Form F in the Appendix, signed by not less than five Members or Associate Members, which shall be laid before the next meeting of Council for their approval. On their approval being given, the Secretary shall notify the same to the Candidate according to Form G; but his name shall not be added to the list of Members or Associate Members until he shall have signed the Form H, and shall have paid the additional entrance fee (if any), and the additional subscription (if any) for the current year.

ELECTION OF PRESIDENT, VICE-PRESIDENTS, AND MEMBERS OF COUNCIL.

25. Candidates shall be put in nomination at the General Meeting preceding the Annual General Meeting, when the Council are to present a list of their retiring Members who offer themselves for re-election; any Member or Associate Member shall then be entitled to add to the list of Candidates. The ballot list of the proposed names shall be forwarded to the Members and Associate Members. The ballot lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

APPOINTMENT AND DUTIES OF OFFICERS.

26. The Treasurer shall be a Banker, and shall hold the uninvested funds of the Institution, except the moneys in the hands of the Secretary for current expenses. He shall be appointed by the Members and Associate Members at a General or Special Meeting, and shall hold office at the pleasure of the Council.

27. The Secretary of the Institution shall be appointed, as and when a vacancy occurs, by the Members and Associate Members at a General or Special Meeting, and shall be removable by the Council upon six months' notice from any day. The Secretary shall give the same notice. The Secretary shall devote the whole of his time to the work of the Institution, and shall not engage in any other business or profession.

28. It shall be the duty of the Secretary, under the direction of the Council, to conduct the correspondence of the Institution; to attend all meetings of the Institution, and of the Council, and of Committees; to take minutes of the proceedings of such meetings; to read the minutes of the preceding meetings, and all communications that he may be ordered to read; to superintend the publication of such papers as the Council may direct; to have the charge of the library; to direct the collection of the subscriptions, and the preparation of the account of expenditure of the funds; and to present all accounts to the Council for inspection and approval. He shall also engage (subject to the approval of the Council) and be responsible for all persons employed under him, and set them their portions of work and duties. He shall conduct the ordinary business of the Institution, in accordance with the Articles and By-laws and the directions of the President and Council; and shall refer to the President in any matters of difficulty or importance, requiring immediate decision.

MISCELLANEOUS.

29. All Papers shall be submitted to the Council for approval, and after their approval shall be read by the Secretary at the General Meetings, or by the Author with the consent of the Council; or, if so directed by the Council, shall be printed in the Proceedings without having been read at a General Meeting.

30. All books, drawings, communications, &c., shall be accessible to the members of the Institution at all reasonable times.

31. All communications to the Meetings shall be the property of the Institution, and be published only by the authority of the Council.

32. None of the property of the Institution—books, drawings, &c.—shall be taken out of the premises of the Institution without the consent of the Council.

33. All donations to the Institution shall be enumerated in the Annual Report of the Council presented to the Annual General Meeting.

34. The General Meetings shall be conducted as far as practicable in the following order:—

1st. The Chair to be taken at such hour as the Council may direct from time to time.

2nd. The Minutes of the previous Meeting to be read by the Secretary, and, after being approved as correct, to be signed by the Chairman.

3rd. The Ballot Lists, previously opened by the Council, to be presented to the Meeting, and the new Members, Associate Members, Graduates, and Associates elected to be announced.

4th. Papers approved by the Council to be read by the Secretary, or by the Author with the consent of the Council.

35. Each Member or Associate Member shall have the privilege of introducing one friend to any of the Meetings; but, during such portion of any meeting as may be devoted to any business connected with the management of the Institution, visitors shall be requested by the Chairman to withdraw, if any Member or Associate Member asks that this shall be done.

36. Every Member, Associate Member, Graduate, Associate, or Visitor, shall write his name and residence in a book to be kept for the purpose, on entering each Meeting.

37. The President shall ex officio be member of all Committees of Council.

38. Seven clear days' notice at least shall be given of every meeting of the Council. Such notice shall specify generally the business to be transacted by the meeting. No business involving the expenditure of the funds of the Institution (except by way of payment of current salaries and accounts) shall be transacted at any Council meeting unless specified in the notice convening the meeting.

39. The Council shall present the yearly accounts to the Annual General Meeting, after being audited by a professional accountant, who shall be appointed annually by the Members and Associate Members at a General or a Special Meeting, at a remuneration to be then fixed by the Members and Associate Members.

40. Any member wishing to have a copy of the Papers sent to him for consideration beforehand can do so by sending in his name once in each year to the Secretary; and a copy of all Papers shall then be forwarded to him as early as possible prior to the date of the Meeting at which they are intended to be read.

41. At any Meeting of the Institution any member shall be at liberty to re-open the discussion upon any Paper which has been read or discussed at the preceding Meeting; provided that he signifies his intention to the Secretary at least one month previously to the Meeting, and that the Council decide to include it in the notice of the Meeting as part of the business to be transacted.

APPENDIX.

FORM A.

Mr. being years of age, and desirous of admission into The Institution of Mechanical Engineers, we, the undersigned proposer and seconder from our personal knowledge, and the three other signers from trustworthy information, propose and recommend him as a proper person to belong to the Institution.

Witness our hands, this day of

Members or Associate Members.

FORM B.

Mr. born on being desirous of admission into The Institution of Mechanical Engineers, we, the undersigned proposer and seconder from our personal knowledge, and the other signer or signers from trustworthy information, propose and recommend him as a proper person to become a Graduate thereof.

Witness our hands, this day of

Members or Associate Members.

FORM C.

If elected an of The Institution of Mechanical Engineers, I, the undersigned, do hereby engage to ratify my election by signing the form of agreement and paying the entrance fee and annual subscription in conformity with the By-laws.

Witness my hand, this day of

FORM D.

Sir,—I have to inform you that on the you were elected a of The Institution of Mechanical Engineers. For the ratification of your election in conformity with the rules, it is requisite that the enclosed form be returned to me with your signature, and that your Entrance Fee and first Annual Subscription be paid, the amounts of which are and respectively. If these be not received within two months from the present date, the election will become void.

I am, Sir, Your obedient servant,

Secretary.

FORM E.

I, the undersigned, being elected a of The Institution of Mechanical Engineers, do hereby agree that I will be governed by the regulations of the said Institution, as they are now formed or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of

FORM F.

Mr. being years of age, and desirous of being transferred into the class of of The Institution of Mechanical Engineers, we, the undersigned, from our personal knowledge recommend him as a proper person to be so transferred by the Council.

Witness our hands, this day of ,

Members or Associate Members.

FORM G.

Sir,—I have to inform you that the Council have approved of your being transferred to the class of of The Institution of Mechanical Engineers. For the ratification of your transference in conformity with the rules, it is requisite that the enclosed form be returned to me with your signature, and that your additional Entrance Fee and additional Annual Subscription for the current year be paid, the amounts of which are and respectively. If these be not received within two months from the present date, the transference will become void.

I am, Sir, Your obedient servant,

Secretary.

FORM H.

I, the undersigned, having been transferred to the class of of The Institution of Mechanical Engineers, do hereby agree that I will be governed by the regulations of the said Institution, as they now exist, or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of

The Institution of Mechanical Engineers.

PROCEEDINGS.

February 1899.

The Fifty-second Annual General Meeting of the Institution was held in the new House of the Institution, St. James's Park, London, on Thursday, 9th February 1899, at Half-past Seven o'clock p.m.; Samuel W. Johnson, Esq., Retiring President, in the chair, succeeded by Sir William H. White, K.C.B., LL.D., D.Sc., F.R.S., President elected at the Meeting.

The President congratulated the Members of the Institution on being this evening for the first time assembled in the lecture hall of their own House. The building occupied a most unique and a most commanding position; it was substantially and elegantly built, and was one of which they could all feel justly proud. Fifty-two years ago, on 27th January 1847, the first meeting of the Institution took place at the Queen's Hotel, Birmingham, with George Stephenson as first President in the chair. There were at that time three Vice-Presidents, Joseph Miller of London, Charles F. Beyer of Manchester, and James Edward McConnell of Wolverton. There were also five Members of Council, all well known in the engineering world, namely Edward Humphrys of London, Benjamin Fothergill of Manchester, Joseph Radford of Manchester, William Buckle of Soho, and Edward A. Cowper of Smethwick. The number of the original members who joined in constituting the Institution at that date was fifty-six. Today the number of members of all classes on the roll of the Institution amounted to 2,684. Since 1847, up to last year 1898, there had

(The President.)

been twenty-three Presidents, among whom were many of the most distinguished and most eminent engineers of the last half-century, whose names were prominently and indelibly interwoven with the national and engineering history of this period. All these Presidents had been concisely referred to, and their achievements recapitulated, by Mr. Windsor Richards in his presidential address at the Jubilee Meeting in Birmingham in July 1897. The Institution had been so successful hitherto, that he thought it was quite fair to anticipate it would meet with still greater success in the future; considering indeed the advantages which would be afforded by the Institution Building in the way of increased facilities and convenience for the members, it was more than probable that it would continue to be a material factor in forwarding the engineering prosperity, not only of Great Britain and her Colonies, but of the whole world. The date and arrangements had not yet been definitely settled for the new building to be formally opened; but probably the inauguration would take place some time in May, under the auspices of Sir William H. White as President. The opening ceremony, which he was sure the members would all agree with him could not possibly have fallen into better hands than Sir William's, would be duly announced at the proper time.

On behalf of the Council he had to express the deep regret which was felt at the loss by death, since the last meeting in October, of Sir William Anderson, K.C.B., whose high position and eminent attainments were well known to all; he had been the President of the Institution in the years 1892 and 1893. Also they had to regret the death of Sir John Fowler, Bart., K.C.M.G., and Mr. Robert Sinclair, the latter having been an eminent locomotive engineer; both had joined the Institution in 1847, the year of its commencement. And even so recently as two days ago they had to deplore the death of Mr. William Laird, who was so well known to all the members, and had been a Member of Council for the last twelve years.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following eighty-one candidates were found to be duly elected :—

MEMBERS.

Barley, Clement Johnson, . .	London.
Bottomley, John William, . .	Leeds.
Bowler, Thomas, ...	Leeds.
Bruce, Graham Stewart, . .	Negapatam.
Buchanan, James, ...	Liverpool.
Copperthwaite, Ralph Atkinson, .	Middlesbrough.
Coveney, William Charles, . .	Singapore.
Dania, George, ...	London.
Dewrance, John, ...	London.
Ditchburn, Robert, . . .	Bombay.
Gardner, William, . . .	London.
Hatch, William Thomas, . .	London.
Hodgson, Henry, ...	Manchester.
Humphrey, Herbert Alfred, . .	Northwich.
Hutson, Charles Alfred, . .	Colombo.
James, Thomas, ...	Derby.
Marsland, John Samuel, . .	Halifax.
McLaren, Richard Andrew, . .	London.
Mills, William, ...	Manchester.
Musgrave, John Richard, . .	Leeds.
Ormsby, Alfred Stewart Augustus, .	London.
Parrack, William Thomas, . .	London.
Thackeray, Thomas, . . .	London.
Warren, Frederick Fridlezius, .	Dublin.

ASSOCIATE MEMBERS.

Begbie, William, ...	Johannesburg.
Beven, Alfred Nugent, . . .	Junin, Chile.
Blissett, Percival Thomas, . .	Bristol.
Carrack, John William, . . .	Nottingham.
Cater, John McIlvaine, . . .	London.

Clark, George, ...	London.
Clerk, Archibald, ...	London.
Collins, William Lorenzo, . .	London.
Day, Claud Albert Stainton, . .	London.
Douglas, Williams Saunders, . .	Consett.
Gale, Robert Harry, . . .	Wisbech.
Goulstone, Ernest Edwin, . .	Cawnpore.
Green, John Singleton, . . .	Manchester.
Hughes, Francis Edward Harold, .	London.
Marshall, Launcelot Paul, . .	Norwich.
Maw, Henry, ...	London.
McAll, Henry Wardlaw, . .	Red Hill.
McBean, John, ...	Boksburg.
McCormack, Arthur John, . .	London.
McTaggart, John, ...	Bradford.
Muirhead, David, ...	Nottingham.
Munn, John Adam, ...	Calcutta.
Pearce, Standen Leonard, . .	London.
Pigott, Arthur, ...	London.
Pilling, Frederick Stott, . .	Blackpool.
Prockter, Frederick Malcolm, .	Liverpool.
Pugh, John Vernon, . . .	Coventry.
Quilter, Frederic Russell. . .	London.
Radley, Bertram Vernon, . .	Asansol, India.
Rochat, Henri Louis, ...	Calcutta.
Rowe, John, ...	Johannesburg.
Secchi, Leopold, ...	London.
Sheffield, Frederick Gerard, .	Norwich.
Slingsby, Walter, ...	Halifax.
Smith, Francis Sumner, . . .	London.
Speight, James William, . .	Blackpool.
Spiller, Claude, ...	Woolwich.
Taverner, Herbert Lacy, . .	Newcastle-on-Tyne.
Tennant, William John, . .	London.
Thomas, Hubert Robert, . .	Wednesbury.
Thomas, Owen Powell, . . .	Colombo.

Thornycroft, John Edward,	London.
West, Haarlem Ethneen,	London.
Whitehouse, Alfred,	Birmingham.

ASSOCIATES.

Sachs, Edwin Otho,	London.
Smith, George Robert,	Leeds.
Wilson, James Michael Graham,	London.

GRADUATES.

Bradley, Cecil Gustav,	Wolverhampton.
Brooks, Harry Gordon,	London.
Dimes, Charles William,	London.
Gandon, Philip George,	London.
Good, Basil Price,	London.
Lowsley, Sydney Evan,	Wolverhampton.
Parsonage, William Rawlett,	Birmingham.
Pashby, Arthur Harold,	London.
Smith, Raymond Berkeley,	London.
Warren, Robert Augustus,	Manchester.

The following six Transferences to the class of Members had been made by the Council since the last General Meeting:—

Dickinson, Harold (*Associate Member*),	Leeds.
Harrison, Frank (*Associate Member*),	Calcutta.
House, Henry A., Jun. (*Associate Member*),	Cowes.
Manton, Arthur Woodroffe (*Associate Member*),	London.
Marshall, Lewis (*Associate*),	Halifax.
Naylor, Sam (*Associate*),	Halifax.

The following Annual Report of the Council was then read:—

ANNUAL REPORT OF THE COUNCIL.

1899.

The Council have the pleasure of presenting to the Fifty-second Annual General Meeting of the Members the following Report of the progress and work of the Institution during the past year.

At the end of last year the number of names in all classes on the roll of the Institution was 2,684, as compared with 2,493 at the end of the previous year, showing a net gain of 191. During 1898 there were added to the register 279 names; against which the loss by decease was 32, and by resignation or removal 56. These figures represent a slight decrease in losses, and also show that 55 more new members were added to the Institution than during the previous year, and 96 more than in the year 1896.

During 1898 Her Majesty has conferred upon Mr. T. Edward Vickers a Companionship of the Order of the Bath, and upon Mr. James Dredge a Companionship of the Order of St. Michael and St. George.

The following forty-seven Deceases of Members of the Institution have occurred during the past year:—

ALLEY, STEPHEN,	Glasgow.
ANDERSON, SIR WILLIAM, K.C.B., D.C.L., F.R.S.,	Woolwich.
BARRIE, WILLIAM,	Yokohama.
BECKWITH, JOHN HENRY,	Manchester.
BESSEMER, SIR HENRY, F.R.S.,	London.
BICKLE, THOMAS EDWIN,	Plymouth.
BICKNELL, EDWARD,	Bath.
BLACK, JAMES MARK,	Londonderry.
BORODIN, ALEXANDER,	St. Petersburg.
BRAND, DAVID JOLLIE (deceased 1897),	Queensland.
CLARK, CHRISTOPHER FISHER,	Wigan.

Cochrane, Charles, ...	Stourbridge.
Dobson, Sir Benjamin Alfred, ...	Bolton.
Douglass, Sir James Nicholas, F.R.S., . . .	Ventnor.
Drummond, Richard Oliver Gardner, . .	Johannesburg.
Eden, The Hon. Francis Fleetwood, . . .	Buenos Aires.
Edlin, Herbert William (deceased 1897). . .	Johannesburg.
Fowler, Sir John, Bart., K.C.M.G., . . .	London.
Gauntlett, William Henry, ...	Middlesbrough.
Gjers, John, ...	Middlesbrough.
Gledhill, Manassah, ...	Manchester.
Gottschalk, Alexandre, ...	Paris.
Hall, George Edward, ...	Manchester.
Hayter, Harrison, ...	London.
Hopkins, John Satchell, ...	Birmingham.
Hopkinson, John, Jun., D.Sc., F.R.S., . . .	London.
Hulse, Joseph Whitworth, ...	Manchester.
Menzies, William, ...	Newcastle-on-Tyne.
Mudd, Thomas, ...	West Hartlepool.
Pearce, Richard, ...	Howrah, Bengal.
Philipson, John, ...	Newcastle-on-Tyne.
Rawlins, John, ...	Birmingham.
Richards, Lewis, ...	Bedlinog, Glam.
Robertson, William, ...	London.
Schram, Richard, ...	London.
Shenton, James, ...	Manchester.
Sinclair, Robert, ...	London.
Spence, John C. (Associate Member), . . .	Johannesburg.
Stoker, Frederick William, ...	Johannesburg.
Strype, William George, ...	Dublin.
Swale, Gerald (Graduate), ...	Victoria, B.C.
Thomasson, Lucas (Associate Member). . . .	Hatfield.
Westwood, Joseph, ...	Barkway, Herts.
Whittem, Thomas Sibley, ...	Coventry.
Williams, William Lawrence, ...	London.
Wilson, Joseph William, ...	London.
Wilson, Robert, F.R.S.E., ...	London.

Of these Sir William Anderson, Director-General of Ordnance Factories, was a Vice-President for four years during his terms of 1879–1885 and 1887–1891 as Member of Council, after which he was elected President for two years, 1892–3; Sir Henry Bessemer was a Member of Council from 1871 to 1878; Mr. Cochrane served

on the Council from 1864 until he became President in 1889, having been a Vice-President for thirteen years; Sir Benjamin A. Dobson was a Member of Council from 1885 until his death, with the exception of the years 1892 and 1893; Sir James N. Douglass entered the Council in the same year, and was a Vice-President from 1889 to 1894, when he retired from ill health; Dr. John Hopkinson was a Member of Council from 1889; and Mr. Mudd from 1896. Sir John Fowler and Mr. Robert Sinclair were elected Members of the Institution in October 1847.

The following twenty-one gentlemen have ceased to be Members of the Institution during the past year:—

BOYER, ROBERT SKEFFINGTON,	Cardiff.
COMMON, JOHN FREELAND FERGUS,	Cardiff.
ETCHES, HARRY,	Brantford, Canada.
EVANSON, FREDERIC MACDONNELL,	Manchester.
FAUVEL, CHARLES JAMES (Associate),	London.
HANSELL, ROBERT BLACKWELL,	Baltimore.
HEINRICH, HERBERT RODOLPH (Graduate),	Chertsey.
HOLT, ROBERT,	London.
HULLAH, ARTHUR,	Bombay.
HUMPHRIES, EDWARD THOMAS,	Pershore.
IVATTS, LIONEL EDWARD,	Behobie, France.
KANTHACK, RALPH,	London.
KNIGHT, BERTRAND THORNTON,	Bangkok.
MÜLLER, HENRY ADOLPHUS,	Calcutta.
NELSON, ARTHUR DAVID,	Sydney.
PAULSON, SCOTT,	Cape Town.
RAFAREL, WILLIAM CLAUDE,	Barnstaple.
REDIT, DAVID,	Downham Market.
SMITH, WILLIAM,	Sydney.
STEWARD, GEORGE RICHARD,	London.
THOMSON, ROBERT MCNIDER,	Kobe, Japan.

In addition to these, thirty-five Resignations of membership took effect on 1st January 1898.

The Accounts for the year ending 31 December 1898 are now submitted to the Members (see pages 14–18) after having been

passed by the Finance Committee, and certified by Mr. Robert A. McLean, chartered accountant, the auditor appointed by the Members at the last Annual General Meeting. The receipts during the year were £8,452 4*s.* 0*d.*, including the amount of £167 6*s.* 3*d.* over-reserved in the previous year, while the expenditure was £7,588 12*s.* 11*d.*, leaving a balance of receipts over expenditure of £863 11*s.* 1*d.* The financial position of the Institution at the end of the year is shown by the balance sheet: the total investments and other assets amount to £66,462 18*s.* 4*d.*; and deducting therefrom the £25,000 of debentures, and allowing £432 13*s.* 9*d.* for accounts owing but not yet rendered (irrespective of the work in progress for the House), and £81 4*s.* 1*d.* unclaimed Debenture Interest, the capital of the Institution amounts to £40,949 0*s.* 6*d.* Of this sum £5,000 has been set aside as a sinking fund for the redemption of the debentures, leaving a balance of £35,949 0*s.* 6*d.* The sum of £15,403 4*s.* 4*d.* still remains invested in Railway Debenture and India Stocks and Consols, registered in the name of the Institution, while £47,544 8*s.* 6*d.* has already been expended on account of the Institution House. It will be seen from the balance sheet that, for the first time for many years past, the actual cost of the Investments, instead of their market value, is given in the assets, thus reducing the balance by nearly £3,000. The certificates of the securities have been duly audited by the Finance Committee and the auditor.

The progress of the Institution House at Storey's Gate, St. James's Park, has occupied the close attention of the Council during the year; and, although several delays have been caused by the completion of necessary agreements with the County Council and other bodies, your Council congratulate the Members on being able at last to enter with the new year into the occupation of our own commodious premises.

Experiments for the Research Committee on the Value of the Steam-Jacket have been carried on at University College, London, by Professor Beare. These have been recorded, and the Committee, under the chairmanship of Mr. Henry Davey, have decided on a

further modification of the experimental apparatus and additional experiments before presenting their next Report.

Sir William C. Roberts-Austen has carried to a successful conclusion a long series of experiments which he has been making for the Institution in his laboratory at the Royal Mint on the behaviour of Steels during cooling; and his Fifth Report, dealing with the structure and properties of various steels containing different percentages of carbon, has been presented to the Alloys Research Committee, and adopted by them for reading and discussion at the present Meeting. The Committee at their recent Meeting elected Sir William H. White as their chairman, in the place of the late Sir William Anderson.

Professor F. W. Burstall's First Report to the Gas-Engine Research Committee, consisting of a description of apparatus and methods and preliminary results, was read and discussed at the Spring Meeting, and called forth useful comment from the Members who took part in the discussion. The Committee, under the chairmanship of Professor Kennedy, are continuing their investigations with the experimental gas-engine at Mason University College, Birmingham.

The compound steam-engine has now been fixed at King's College, London, for the Steam-Engine Research Committee. The chairman, Mr. Bryan Donkin, and the reporter, Professor Capper, hope to commence a series of experiments early this year.

For the additions to the Library of the Institution which have been received by presentation and exchange during the past year, as enumerated in pages 20–27, the Council here record their thanks to the several Donors. As the restricted library accommodation hitherto available in the old offices of the Institution is now succeeded by the ampler space provided in the new building, the Council look upon this enlargement as presenting a peculiarly favourable opportunity for welcoming from Members who have published works

valuable for reference, or original pamphlets on engineering subjects, or records of experiments, copies of such publications for permanent preservation, and for enhancing the value of the Library.

The General Meetings in 1898 were the Annual General Meeting and the Spring Meeting, both held in London; the Summer Meeting in Derby; and the Autumn Meeting in London. Altogether eight sittings were occupied in the reading and discussion of ten of the following Papers, which are published in the Proceedings:—

Mechanical features of Electric Traction; by Mr. Philip Dawson.

Diagrams to facilitate the design of Riveted Joints for Boiler Work; by Professor W. E. Dalby.

Address by the President, Samuel W. Johnson, Esq.

First Report to the Gas-Engine Research Committee: description of apparatus and methods, and preliminary results; by Professor Frederic W. Burstall.

Steam Laundry Machinery; by Mr. Sidney Tebbutt.

Aluminium Manufacture, with description of the Rolling Mills and Foundry at Milton, Staffordshire; by Mr. E. Ristori.

Narrow-Gauge Railways, of two feet gauge and under; by Mr. Leslie S. Robertson.

Water Softening and Purification by the Archbutt-Deeley Process; by Mr. Leonard Archbutt.

Electric Installations for Lighting and Power on the Midland Railway, with notes on Power absorbed by Shafting and Belting; by Mr. W. E. Langdon.

Results of recent practical experience with Express Locomotive Engines; by Mr. Walter M. Smith.

Mechanical Testing of Materials at the Locomotive Works of the Midland Railway, Derby; by Mr. W. Gadsby Peet.

The attendances during 1898 were as follows:—at the Annual General Meeting 136 Members and 113 Visitors; at the Spring Meeting 130 Members and 57 Visitors; at the Summer Meeting 512 Members and 81 Visitors; and at the Autumn Meeting 132 Members and 80 Visitors. These figures show an improvement in the attendance of members amounting to 54 per cent., 106 per cent., 26 per cent., and 48 per cent. respectively at the four meetings of the Institution, the largest increase being at the reading and discussion of Papers in London.

The President's Address, dealing with the History of the Midland Railway and its Rolling Stock, was delivered at the Spring Meeting, and has attracted considerable attention throughout the railway world.

The Summer Meeting was held in Derby, the headquarters of all the engineering departments of the Midland Railway, of which the Chairman and Directors granted substantial facilities to individual Members attending the Meeting. In the three Papers read important subjects of special local interest were dealt with, and were well discussed. Subsequently the Members were able to add to their interest in each of these subjects by visiting the British Aluminium Works at Milton, the water-softening apparatus of the Midland Railway and several small villages, and the Duffield Bank narrow-gauge railway, in addition to a large number of works in Derby and Nottingham and the neighbourhood. Excursions were made to Stoke, Burton, Loughborough, Swithland, Nottingham, and the Dukeries. The Members were also hospitably entertained by the President at a garden party in the grounds of Nottingham Castle; and by the Local Committee, under the chairmanship of Sir A. Seale Haslam, at a conversazione in the Derby Art Gallery. The work of arranging the details of the programme was ably carried out by Mr. R. Mountford Deeley and Mr. George J. Pratt of Derby as joint Honorary Secretaries; and the Council have marked their appreciation of their active exertions by presenting to each on behalf of the Members a silver salver, bearing an inscription recording their grateful acknowledgment of the services rendered.

The Council purpose holding the Summer Meeting of the Institution this year in Plymouth.

Several Members of the Council have given evidence before the National Physical Laboratory Committee; others have represented the Institution at the Autumn Congress of the Sanitary Institute in Birmingham, and at the Jubilee Meeting of the French Society of Civil Engineers in Paris. The Council are in consultation with the

Association of Technical Institutions for the purpose of encouraging their most promising students to affiliate themselves with this Institution.

At this Meeting the Members have to elect a President, three Vice-Presidents, and seven Members of Council, to fill the vacancies caused by retirement and by death. The result of the ballot for these elections will be announced to the Meeting. The Council regret to inform the Members that the President is unable to accept office for the ensuing year, owing to other important duties making too great demands upon his time; they have therefore nominated Sir William H. White for the presidency, and he has accepted the nomination.

Dr. ACCOUNT OF EXPENDITURE AND RECEIPTS

Expenditure.	£	s.	d.	£	s.	d.
To Editing, Printing, and Engraving Proceedings	2,040	17	10			
„ Reprinting former Proceedings	21	4	0			
	2,062	1	10			
Less Authors' Copies of Papers, repaid	5	11	6	2,056	10	4
„ Stationery and General Printing				257	6	1
„ Binding				28	14	4
„ Rent of Offices (19 Victoria Street)				710	0	0
„ Salaries and Wages				2,063	17	6
„ Coal, Firewood, and Lighting				50	7	1
„ Fittings and Repairs				27	6	11
„ Postages, Telegrams, and Telephone				328	12	1
„ Insurance				42	7	9
„ Travelling Expenses				3	13	4
„ Petty Expenses				51	16	9
„ Meeting Expenses—						
Printing	286	17	9			
Reporting	51	14	0			
Diagrams, Screen, &c.	111	14	1			
Travelling and Incidental Expenses	172	5	10	622	11	8
„ Dinner Guests				56	4	10
„ Research				217	8	10
„ Books purchased				27	7	4
„ Removal (part)				44	8	0
„ Debenture Interest				1,000	0	1
				7,588	12	11
Balance, being excess of Receipts over Expenditure, carried down—				863	11	1
				£8,452	4	0
To Honorarium to retiring Secretary				3,000	0	0
To House for Institution—						
Expended on Building this year	16,257	19	7			
Ground Rent during construction	850	8	2	17,108	7	9
Cash Balance 31st December 1898	1,495	1	5			
Add amount over-reserved as above	167	6	3	1,662	7	8
				£21,770	15	5

FOR THE YEAR ENDING 31st DECEMBER 1898. *Cr.*

Receipts.	£	s.	d.	£	s.	d.
By Entrance Fees—						
124 *New Members at £2*	248	0	0			
103 *New Associate Members at £1*	103	0	0			
13 *New Associates at £1*	13	0	0			
14 *Associate Members transferred to Members at £1*	14	0	0			
2 *Associates transferred to Members at £1*	2	0	0			
1 *Graduate transferred to Member at £1*	1	0	0	381	0	0
„ Subscriptions for 1898—						
1747 *Members at £3*	5,241	0	0			
361 *Associate Members at £2 10s.*	902	10	0			
81 *Associates at £2 10s.*	202	10	0			
184 *Graduates at £1 10s.*	276	0	0			
14 *Associate Members transferred to Members at 10s.*	7	0	0			
2 *Associates transferred to Members at 10s.*	1	0	0			
1 *Graduate transferred to Member at £1 10s.*	1	10	0			
4 *Graduates transferred to Associate Members at £1*	4	0	0	6,635	10	0
„ Subscriptions in arrear—						
70 *Members at £3*	210	0	0			
12 *Associate Members at £2 10s.*	30	0	0			
2 *Associates at £2 10s.*	5	0	0			
2 *Graduates at £2*	4	0	0			
16 *Graduates at £1 10s.*	24	0	0	273	0	0
„ Subscriptions in advance—						
25 *Members at £3*	75	0	0			
1 *Associate Member at £2 10s.*	2	10	0			
2 *Associates at £2 10s.*	5	0	0			
3 *Graduates at £1 10s.*	4	10	0			
	87	0	0			
Less 1 *Graduate at £1 10s., refunded*	1	10	0	85	10	0
„ Interest—						
From Investments	743	7	0			
From Bank	17	10	7			
Income Tax refunded (3 *years*)	75	15	6	836	13	1
„ Reports of Proceedings—						
Extra Copies sold				73	4	8
„ Reserve in previous year against accounts owing	600	0	0			
Less general accounts owing, not yet rendered	432	13	9			
				167	6	3
				£8,452	4	0

	£	s.	d.
By Balance brought down	863	11	1
By Life Compositions	212	0	0
By Sale of Investments	16,642	13	0
Cash Balance 31st December 1897	4,052	11	4
	£21,770	15	5

Dr. BALANCE SHEET

			£ s. d.
To Debentures—			
250 *of* £100 *each at* 4%, *redeemable in* 1917, *or at par at any date after* 1*st Jan.* 1908, *on six months' notice to holder*			25,000 0 0
„ Sundry Creditors—			
Accounts owing, not yet rendered, say	432 13 9		
Unclaimed Debenture Interest	81 4 1		513 17 10
Capital of the Institution :—			
(1) *Excess of Assets over Liabilities at this date*	35,949 0 6		
(2) *Set aside during* 1897–98 *as a Sinking Fund for redemption of Debentures* .	5,000 0 0		40,949 0 6*
(exclusive of back numbers of Proceedings, which cost £5,200)			
			£66,462 18 4

* Note.—*The diminution in this Balance as compared with last year is chiefly in consequence of the Finance Committee having decided that now and for the future the Cost of the Investments, instead of their Market Value, shall rank in the Assets.*

Signed by the following members of the Finance Committee:—

E. WINDSOR RICHARDS, WILLIAM H. MAW,
DOUGLAS GALTON, BRYAN DONKIN,
ARTHUR KEEN, JOHN G. MAIR-RUMLEY.

AS AT 31ST DECEMBER 1898. *Cr.*

				£	s.	d.
By House for Institution, expenditure to date				47,544	8	6
„ Investments . . . *cost*				15,403	4	4
£ 4,237 *London and North Western Ry.* 3% *Debenture Stock*						
3,945 12*s*. *Midland Railway* 2½% „ „						
4,053 *India* 3% *Stock*						
5,000 *Consols* 2¾%						
The Market Value of these investments at 31*st Dec.* 1898 *was about* £18,281, *of which* £5,000 *is reserved for the Sinking Fund.*						
			£ s. d.			
„ Cash—*In Union Bank, on Current account*			995 1 5			
In London Joint Stock Bank	342 11 7					
Cash balance at 3rd Dec. 1898 (when expenditure account closed) since spent	157 8 5		500 0 0	1,495	1	5
In Union Bank, unclaimed Debenture Interest				81	4	1
„ Library				1,240	0	0
„ Subscriptions in Arrear, probable value				256	0	0
„ Office Furniture and Fittings				343	0	0
„ Drawings, Engravings, Models, Specimens, and Sculpture				100	0	0
„ Proceedings, back numbers, cost £5,200						
				£66,462	18	4

Audited and Certified by

ROBERT A. McLEAN, F.C.A.,
Auditor,
1 Queen Victoria Street, London, E.C.

WILLANS PREMIUM FUND.

Investment £159 8s. 5d. of India 3% Stock . . . . cost £165 5s. 0d.

Dr.	£	s.	d.	*Cr.*	£	s.	d.
To Institution of Electrical Engineers . . .	11	18	4	By Interest, 1895-96-97	11	18	4
" Balance, held in trust .	4	15	4	" " 1898 . .	4	15	4
	£16	13	8		£16	13	8

Audited, certified, and signed by the names on pages 16-17

The next award of the Premium at the end of the year 1900 devolves upon the Council of this Institution.

DECLARATION OF TRUST OF THE WILLANS PREMIUM FUND.

To all to whom these presents shall come The Institution of Mechanical Engineers and The Institution of Electrical Engineers send greeting. Whereas a Fund has been subscribed by the friends of the late PETER WILLIAM WILLANS, of Thames Ditton, for the purpose of commemorating his name and the services which he rendered to Engineering and Electrical science; and at the request of the subscribers to the said fund the above-named Institutions have agreed to act as joint Trustees thereof, and the sum of One hundred and sixty-five pounds has accordingly been paid to the said Institutions: now these presents witness that the said Institutions do hereby declare the Trusts upon which they hold the said fund to be as follows:—

1. To invest the said fund upon such securities as trustees are by law authorised to hold, and in such names as the Councils of the two Institutions shall from time to time direct.

2. To apply the proceeds of the said investment as and

when received, after payment of any expenses incidental to the administration of the trust, to the Premium hereinafter described, to be known as "the Willans Premium."

3. The Willans Premium shall be awarded alternately by the Council of each of the above-mentioned Institutions; and first by The Institution of Electrical Engineers in December 1897.

4. The Council of the awarding Institution in each alternate period shall award the Willans Premium for the best original paper communicated to their Institution, dealing with such a general subject as the utilisation or transformation of energy, treated especially from the point of view of efficiency or economy: provided that the Premium shall not be awarded unless a paper of sufficient merit in the judgment of the awarding Council shall have been so communicated since the preceding award of that Council.

5. The Premium shall be awarded triennially in and after December 1897, unless otherwise determined by resolution of the respective Councils of the two Institutions.

6. The Premium may be awarded either in money or books or medal, or in any other form which in the instance of any individual award the awarding Council may then determine.

7. In case of no award at the end of any triennial period, the premium available for that award shall be added to the capital of the fund.

In witness whereof The Institution of Mechanical Engineers have hereunto affixed their common seal, and the President and Secretary of The Institution of Electrical Engineers have hereunto set their hands, this sixteenth day of January 1895.

The Seal of The Institution of Mechanical Engineers was impressed by the President in the presence of Alfred Bache, Secretary; and the document was signed as follows:—

ALEXANDER B. W. KENNEDY,

President of The Institution of Mechanical Engineers.

R. E. CROMPTON,

President of The Institution of Electrical Engineers.

F. H. Webb, Secretary of The Institution of Electrical Engineers.

LIST OF DONATIONS TO THE LIBRARY.

Message from the President of the U.S. America, transmitting Report upon the destruction of the "Maine"; from the U.S. President.

The Heat Efficiency of Steam Boilers: Land, Marine, and Locomotive, by Bryan Donkin; from the author.

Elements of Machine Construction and Drawing, by H. J. Spooner and E. G. Davey; from the publishers.

Engineering Arithmetic and Mensuration, by C. R. Honiball; from the author.

Cours d'Électricité, théorie et pratique, by C. Sarazin; from the publishers.

Contribution to the History of the Respiration of Man, by William Marcet, M.D., F.R.C.P., F.R.S.; from Mr. James P. Maginnis.

Essays on Social Topics, by Lady Cook; from the authoress.

Manchester Corporation Electricity Department: Rules as to the Supply of Electric Energy; from Mr. C. H. Wordingham.

Reminiscences of Russia in 1897, by J. Cartmell Ridley; from the author.

Light Railways, by Leslie S. Robinson; from the author.

Railway Technical Vocabulary, by L. Serraillier; from the author.

Paris Exhibition, 1900; from Mr. L. Serraillier.

Steam Tables and Engine Constants, by T. Pray, Jun.; Calorimeter Tables for Steam, by T. Pray, Jun.; from the author.

Theta-phi Diagram practically applied to Steam, Gas, Oil, and Air Engines, by H. A. Golding; from the author.

Moteurs à Gaz et à Pétrole, by A. Witz; from the publishers.

The Indicator Handbook, by C. N. Pickworth; from the author.

Aid Book to Engineering Enterprise, by Ewing Matheson; from the author.

Adulteration of Portland Cement, by W. H. Stanger and B. Blount; from the authors.

The Theory and Practice of Electrolytic Methods of Analysis, by Dr. B. Neumann, translated by J. B. C. Kershaw; Alternate Currents in Practice, by F. J. Moffett; from the publishers.

Queensland Past and Present, by T. Weedon; from Mr. John B. Henderson.

Report of the Hydraulic Engineer on the Water Supply of Queensland, 1897; from Mr. John B. Henderson.

Empire of Austria, Patent Law dated 11 January 1897, translated by Paget Moeller and Hardy; from Mr. J. G. Hardy.

Review of the Japanese Patent Law, by W. Silver Hall; from the author.

The following from the U.S. Geological Survey:—Seventeenth Annual Report, Parts I and II, 1895–96; Monographs, XXV–XXVIII (with Atlas) and XXX; Bulletins, 87–89, 127, 130, 135–149.

The following from the U.S. Ordnance Office:—Annual Report of the United States Chief of Ordnance, 1897; Tests of Metals, &c., at Watertown Arsenal, Massachusetts, 1896; Notes on the Construction of Ordnance.

Inaugural Address to the Manchester Association of Engineers by the President, Mr. Henry Webb, 15 January 1898; from the author.

Impermeabilización de Tejidos, by F. Aramburu; from the author.

General Rules recommended for Wiring for the Supply of Electrical Energy; from the Institution of Electrical Engineers.

Rede zum Geburts-feste seiner Majestät des Kaisers und Königs Wilhelm II in der Aula der Königlichen Technischen Hoch-schule zu Berlin, 26 Januar 1898; from the Rector.

Method of Measuring the Pressure at any point on a Structure, due to Wind blowing against that Structure, by Professor F. E. Nipher; from the author.

Tests of the Synchronograph on the Telegraph Lines of the British Government, by Drs. Crehore and Squier; from the authors.

Some Iron and Steel Works of the United States, by Franklin Hilton; from the author.

Torquay Waterworks, by William Ingham; from the author.

Matériel et Procédés de l'Exploitation des Mines à l'Exposition internationale de Bruxelles en 1897, by V. Watteyne and A. Halleux; from Mr. James Dredge, C.M.G.

West Indies and Sugar Bounties.

Tests for Steel Castings (large and small), Capstans and Gear, and Steel Castings for Machinery; Specification for Steel and Steel Wire for Ordnance; from Sir William H. White, K.C.B., LL.D., F.R.S.

List of Chinese Lighthouses, Light-Vessels, Buoys, and Beacons, 1898; from the Inspector General of Chinese Customs.

Construction of Inclined Gas-Retorts, Charging Apparatus, and Conveying Machinery, by M. Graham; from the author.

Clyde Navigation: Description of No. 3 Graving Dock, Glasgow, by J. Deas; from the author.

Notes on American Iron and Steel Practice, by A. P. Head; from the author.

Report of the Kew Observatory Committee, 1897; Notes on Thermometry, by C. Chree; from the Committee.

Marine Boilers, by L. E. Bertin, translated by Leslie S. Robertson; from the translator.

Science and Engineering, 1837–97, by C. Bright; from the publishers.

Note sur l'Unification des Filetages, by F. G. Kreutzberger; from the author.

Suggested Rules for the Recovery of Coal Mines after Explosions, by W. E. Garforth; from the Federated Institution of Mining Engineers.

Ventilation of the Metropolitan Railway Tunnels; from Mr. Edgar Worthington.

Cold Hop Storage, by L. Sterne; from the author.

Proposed High-level Roadway Bridge across the River Mersey at Liverpool; from Mr. John James Webster.

British India's future Standard Currency, by J. H. Norman; from the author.

Ramsgate Corporation Water Department, New Pumping Station: account of Opening Ceremony; from Mr. W. A. M. Valon.

Festschrift zur XXXIX Haupt-versammlungdes Vereines Deutscher Ingenieure. Chemnitz 1898; from the Chemnitz branch of the Verein Deutscher Ingenieure.

Balancing of Engines, by J. Whitcher; from the author.

Lubrication and Traction relating to Railway Carriages, by T. G. Clayton; from the author.

Report of the Inspection of Mines in India, 31 December 1896; from the India Office.

Classification Bibliographique Décimale, by E. Sauvage; from the author.

Minimum-Gauge Railways, their application, construction, and working, by Sir Arthur P. Heywood, Bart.; from the author.

Classified Lists and Distribution Returns of Establishment, Indian Public Works Department, to 31 Dec. 1897 and 30 June 1898; from the Registrar.

Wire Rope and its Applications, by W. E. Hipkins; from the author.

Basic Refined Steel on the Continent, by C. E. Stromeyer; from the author.

Jersey New Waterworks, Bye-laws, Regulations, &c.; from Mr. Hugh G. Foster-Barham.

Evolution of the Locomotive Engine, by W. P. Marshall; from the author.

Instruments for Measuring small Torsional Strains, by E. G. Coker; from the author.

The following official publications from the Government of New South Wales:—
Annual Report of the Railway Commissioners for the year ending 30 June 1898; Reports of the Department of Public Works for the years ending 30 June 1896 and 30 June 1897; Report relating to the proposed duplicate Main from Prospect to Potts' Hill; Report relating to the proposed New Bridge at Glebe Island; three Reports of Royal Commissions to enquire into management of—(1) Hunter District Water Supply and Sewerage Board, (2) Metropolitan Water Supply and Sewerage Board, (3) Working of Mines and Quarries in the Albert Mining District; Wealth and Progress of New South Wales, Vol. II, 1895–6 and 1896–7, by T. A. Coghlan.

Journal of the Society of Mechanical Engineers, Japan, Vol. I, No. I, December 1897; from Professor Bunji Mano.

Local Government Board and the Protection of Water from Pollution, by P. Griffith; from the author.

Commercial Aspect of Engineering, by C. E. Larard; from the author.

Methods of dealing with Condensation, by J. Buley; from the author.

Wellington (N.Z.) Main Drainage, History of the Scheme; from Mr. W. Ferguson.

Liverpool and London and Globe Electrical Installation Rules, Special Risks' Supplement; from the company.

Report on the working of the Megass Lessivage system at Rodah; Perichon system of Megass Lixiviation at Rodah; from Messrs. Greig and Wilson.

Steel Permanent Way, by R. Price-Williams; from the author.

Report of a Visit to Technical Colleges &c. in the United States and Canada, 1898; from the Manchester Technical Instruction Committee.

State of Nicaragua, by G. Niederlein; Republic of Costa Rica; from the Philadelphia Museums.

Neuere Zahn-rad-bahnen, by E. Brückmann; from the author.

Replica di Krupp alla protesta del Signor Bashforth, translation by Rev. F. Bashforth; from the translator.

Report on the working of the Public Works Workshops, Madras, 1897–8; from Mr. H. Moss.

Manchester Electric Trams, Conduit System versus Overhead Trolley, by Hans Renold; from the author.

Under-Frame and Body for a four-wheeled Truck, by L. J. Bika; from the author.

Cinquantenaire de l'Association des Ingénieurs sortis de l'École de Liége; from the Association.

Board of Trade Reports on Boiler Explosions; from the Board of Trade.

Yorkshire College, Leeds, Annual Report, 1896–97; from the College.

University of California, Annual Report of Secretary, 1896; Register, 1896–97; from the University.

City and Guilds of London Institute, Report to the Governors, March 1898; from the Institute.

University College, Sheffield, Calendar 1897–98; from the College.

University College of South Wales and Monmouthshire, Calendar 1897–98; from the College.

Calendars 1898–99 from the following Colleges:—Royal Technical High School, Berlin; Mason University College, Birmingham; Municipal Technical School, Birmingham; University College, Bristol; Cardiff Technical School (Prospectus); Glasgow and West of Scotland Technical College; Yorkshire College, Leeds; City of London College; King's College, London; McGill University, Montreal; Royal Technical High School,

Munich (with Report); University College, Sheffield; Civil Engineering College, Sibpur.

Lockwood's Builder's and Contractor's Price-book, 1898; from the publishers.

Spons' Engineers' and Contractors' Diary and Year-book, 1898; from the publishers.

Engineers' Compendium, 1898; from the publishers.

Abridgments of Specifications of Patents for Inventions, 1889-92—Classes 1-8, 10-19, 21-54, 56-77, 79-81, 84-105, 107-124, 126-146; Catalogue of the Library of the Patent Office, Vol. I, Authors, 1898; from the Patent Office.

Illustrated Catalogue of Machinery and Tools; from Mr. George Hatch.

Illustrated Catalogue of Mathematical Instruments; from Mr. W. F. Stanley.

Illustrated Catalogue of Diving Apparatus; from Messrs. Siebe, Gorman and Co.

Royal Societies Club, List of Members, &c., 1897-8; from the Club.

Illustrated Catalogue of Printing Machines, &c.; from Messrs. Furnival and Co.

Illustrations of Electric Traction; from the British Thomson-Houston Co.

Universal Directory of Railway Officials, 1898; from the publishers.

Donaldson's Engineers' Annual and Almanac, 1899; from Mr. Philip R. Owens.

Baldwin Locomotive Works, Record of recent construction, 1898; from the company.

Water Supply to Villages and Country Houses; from Messrs. Merryweather and Sons.

Standards of Length and their practical application; from the Pratt and Whitney Co.

Fowler's "Mechanical Engineer" Pocket Book, 1899; from the publishers.

Pocket Hand-book of Electro-glazed Luxfer Prisms; from the Luxfer Prism Co.

The following Publications from the respective Societies and Authorities:—

Reports of the Academy of Science, France.

Annales des Ponts et Chaussées, Paris.

Proceedings of the French Institution of Civil Engineers.

Journal of the French Society for the Encouragement of National Industry.

Annales des Mines.

Annales du Conservatoire des Arts et Métiers.

Journal of the Marseilles Scientific and Industrial Society.

Proceedings of the Industrial Society of St. Quentin et de l'Aisne.

Proceedings of the Industrial Society of the North of France.

Proceedings of the Industrial Society of Rouen.

Proceedings of the Industrial Society of Mulhouse.
Bulletins of the French Technical Maritime Association.
Annals of the Association of Engineers of Ghent.
Proceedings of the Society of German Engineers.
Reports of the Royal Academy of Science, Belgium.
Reports of the Royal Institute of Engineers, Holland.
Bulletins of the International Railway Congress.
Proceedings of the Engineers' and Architects' Society of Canton Vaud.
Proceedings of the Engineers' and Architects' Society of Austria.
Proceedings of the Engineers' and Architects' Society of Prague.
Technicky Obzor, Prague.
Proceedings of the Architects' and Engineers' Society of Hannover.
Proceedings of the Italian Engineers' and Architects' Society.
Proceedings of the Engineers' and Architects' Society of Milan.
Proceedings of the Russian Imperial Institute of Engineers.
Proceedings of the Swedish Technical Society.
Journal of the Norwegian Technical Society.
Teknisk Ugeblad, Christiania.
Journal of the Franklin Institute.
Transactions of the American Society of Civil Engineers.
Transactions of the American Society of Mechanical Engineers.
Transactions and Proceedings of the American Philosophical Society.
Journal of the Western Society of Engineers, Chicago.
School of Mines Quarterly, Columbia College, New York.
Reports of the Smithsonian Institution, Washington.
Report of the Master Car-Builders' Association, New York.
Proceedings of the United States Naval Institute.
United States Patent Office Gazette.
Journal of the Association of Engineering Societies.
Journal of the United States Artillery.
Transactions of the Canadian Society of Civil Engineers.
Proceedings and Journal of the Asiatic Society of Bengal.
Transactions of the Australasian Institute of Mining Engineers.
Proceedings of the Engineering Association of New South Wales.
Journal and Proceedings of the Royal Society of New South Wales.
South African Association of Engineers and Architects, Proceedings, Vol. III, 1895-7.
Proceedings of the Institution of Civil Engineers.
Journal of the Iron and Steel Institute.
Transactions of the Society of Engineers.
Journal of the Institution of Electrical Engineers.
Transactions of the Civil and Mechanical Engineers' Society.

Transactions of the North of England Institute of Mining and Mechanical Engineers.
Proceedings of the South Wales Institute of Engineers.
Transactions of the Institution of Engineers and Shipbuilders in Scotland.
Transactions of the Liverpool Engineering Society.
Transactions of the Midland Institute of Mining, Civil, and Mechanical Engineers.
Proceedings of the Cleveland Institution of Engineers.
Transactions of the Mining Institute of Scotland.
Transactions of the North-East Coast Institution of Engineers and Shipbuilders.
Transactions of the Hull and District Institution of Engineers and Naval Architects.
Proceedings of the South Staffordshire Institute of Iron and Steel Works' Managers.
Philosophical Transactions and Proceedings of the Royal Society of London.
Proceedings of the Royal Society of Edinburgh.
Proceedings of the Royal Institution of Great Britain.
Transactions and Professional Notes of the Surveyors' Institution.
Journal of the Royal United Service Institution.
Professional Papers of the Royal Engineers' Institute.
Journal of the Royal Agricultural Society of England.
Report of the British Association for the Advancement of Science.
Transactions of the British Association of Waterworks Engineers.
Report of the Royal Cornwall Polytechnic Society.
Transactions of the Institution of Naval Architects.
Transactions and Journal of the Royal Institute of British Architects.
Transactions of the Incorporated Gas Institute.
Proceedings of the Physical Society of London.
Science Abstracts—Physics and Electrical Engineering.
Proceedings of the Literary and Philosophical Society of Manchester.
Transactions of the Manchester Geological Society.
Journal of the Royal Scottish Society of Arts.
Proceedings of the Philosophical Society of Glasgow.
Transactions of the Institution of Civil Engineers of Ireland.
Transactions and Proceedings of the Royal Irish Academy.
Transactions and Proceedings of the Royal Dublin Society.
Transactions of the Institute of Marine Engineers.
Journal of the Society of Arts.
Journal of the Society of Chemical Industry.
Transactions of the Manchester Association of Engineers.
Transactions of the Institution of Junior Engineers.
Journal of the West of Scotland Iron and Steel Institute.
Annual Report of the Birmingham Association of Mechanical Engineers, 1897.

Publications of the British Fire Prevention Committee.

Reports of the Manchester Steam Users' Association; from the Association.

Report of the Engine, Boiler, and Employers' Liability Insurance Company; from Mr. Michael Longridge.

Forty-fifth Annual Report of the Liverpool Free Public Library.

Forty-sixth Annual Report of the Manchester Public Free Libraries.

Fifteenth Annual Report of the Barrow-in-Furness Free Public Library.

Third Annual Report 1897 of the John Crerar Library, Chicago.

Catalogue of Additions during 1897 to the Radcliffe Library, Oxford.

Annual Report of the Library Syndicate, Cambridge, 1897.

The following Periodicals from the respective Editors:—

Arms and Explosives.
The Builder.
Camera Club Journal.
Cassier's Magazine.
The Colliery Guardian.
The Contract Journal.
Domestic Engineering.
The Electrical Engineer.
The Electrical Review.
The Electrician.
The Engineer.
The Engineer and Iron Trades' Advertiser.
Engineering.
The Engineering Magazine.
The Engineering Record.
The Engineering and Mining Journal.
Engineers' Gazette.
The Fireman.
The Journal of Gas Lighting.
Giornale del Genio Civile.
Glasers Annalen.
Golfing and Cycling Illustrated.
The Indian and Eastern Engineer.
L'Industrie.
Industries and Iron.
El Ingeniero Español.
Invention.
Inventor's Review.
The Iron and Coal Trades Review.
Iron Trade Circular, Ryland's.
The Ironmonger.
Ironmongery.
Lightning.
London Technical Education Gazette.
The Machinery Market.
The Marine Engineer.
The Mariner.
The Mechanical Engineer.
The Mechanical World.
The Mining Journal.
Phillips' Monthly Machinery Register.
The Plumber and Decorator.
The Practical Engineer.
The Public Health Engineer.
The Railway Engineer.
Railway Master Mechanic.
The Railway Review.
Revue générale des Chemins de fer.
Revue universelle des Mines.
The Shipping World.
Stahl und Eisen.
The Steamship.
Street Railway Journal.
Tenders and Contracts.
The Textile Recorder.
Transport.

The PRESIDENT moved the adoption of the Report of the Council with the statement of accounts, and invited any discussion thereon which the Members might wish to raise.

No remarks being offered, the motion was unanimously agreed to.

The PRESIDENT announced that the Ballot Lists for the election of Officers for the present year had been opened by a committee of the Council, and that the following were found to be elected :—

PRESIDENT.

SIR WILLIAM H. WHITE, K.C.B., LL.D., D.Sc., F.R.S., .	London.

VICE-PRESIDENTS.

SIR DOUGLAS GALTON, K.C.B., D.C.L., LL.D., F.R.S., .	London.
WILLIAM H. MAW, ...	London.
T. HURRY RICHES, ...	Cardiff.

MEMBERS OF COUNCIL.

SIR WILLIAM ARROL, M.P., LL.D., ...	Glasgow.
SIR BENJAMIN BAKER, K.C.M.G., LL.D., F.R.S., . .	London.
HENRY DAVEY, ...	London.
EDWARD B. ELLINGTON, ...	London.
THE RIGHT HON. WILLIAM J. PIRRIE, . . .	Belfast.
SIR THOMAS RICHARDSON, M.P., ...	Hartlepool.

For supplying the vacancy amongst the Members of Council, consequent upon the death of Mr. William Laird, the Council had appointed Mr. HENRY CHAPMAN as a Member of Council for the present year, his name being the next highest in the voting for the election at this Meeting. Agreeably with the Articles of Association, he would retire at the next Annual General Meeting, and would be eligible for re-election.

The Council for the present year would therefore be as follows :—

PRESIDENT.

Sir William H. White, K.C.B., LL.D., D.Sc., F.R.S.,	London.

PAST-PRESIDENTS.

The Right Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S.,	Newcastle-on-Tyne.
Sir Lowthian Bell, Bart., F.R.S.,	Northallerton.
Sir Frederick J. Bramwell, Bart., D.C.L., LL.D., F.R.S.,	London.
Sir Edward H. Carbutt, Bart.,	London.
Jeremiah Head,	London.
Samuel Waite Johnson,	Derby.
Alexander B. W. Kennedy, LL.D., F.R.S.,	London.
E. Windsor Richards,	Caerleon.
John Robinson,	Leek.
Percy G. B. Westmacott,	Ascot.

VICE-PRESIDENTS.

Sir Douglas Galton, K.C.B., D.C.L., LL.D., F.R.S.,	London.
Arthur Keen,	Birmingham.
Edward P. Martin,	Dowlais.
William H. Maw,	London.
T. Hurry Riches,	Cardiff.
J. Hartley Wicksteed,	Leeds.

MEMBERS OF COUNCIL.

Sir William Arrol, M.P., LL.D.,	Glasgow.
John A. F. Aspinall,	Horwich.
Sir Benjamin Baker, K.C.M.G., LL.D., F.R.S.,	London.
Henry Chapman,	London.
Henry Davey,	London.

WILLIAM DEAN, ...	Swindon.
BRYAN DONKIN, ...	London.
EDWARD B. ELLINGTON, ...	London.
H. GRAHAM HARRIS, ...	London.
JOHN G. MAIR-RUMLEY, ...	London.
HENRY D. MARSHALL, ...	Gainsborough.
THE RIGHT HON. WILLIAM J. PIRRIE, . . .	Belfast.
SIR THOMAS RICHARDSON, M.P., ...	Hartlepool.
JOHN I. THORNYCROFT, F.R.S., ...	London.
A. TANNETT WALKER, ...	Leeds.

MR. SAMUEL W. JOHNSON said the time had now come when he had to retire from the office of President of the Institution. He had much pleasure in asking Sir William White to take that position. The Institution could not possibly have a better occupant of the chair, especially considering the duties that would have to be fulfilled during the coming year. The Institution House would have to be formally opened; and the members would all have an opportunity of seeing something of the ships of the Royal Navy when they went to the Summer Meeting in Plymouth. All the members of the Institution were expecting a particularly pleasant and instructive year under the guidance of their new President. He had great pleasure therefore in now asking Sir William H. White to take the presidential chair of the Institution.

SIR WILLIAM H. WHITE, on taking the chair as President, thanked the Members most sincerely for the great honour they had done him in electing him to this office, and assured them that to the best of his ability he should serve the interests of the Institution. It might be, it possibly would be, that other engagements which required some considerable time and thought would prevent his doing all he should wish in the service of the Institution; but he begged the Members to believe that, whatever the result might be, he should aim to do his best. There was one passage in the Report of the Council, of which he deeply felt the truth: namely the regret

which all the Members must experience, and he personally perhaps most of all, that Mr. Johnson had not seen his way to continue to act as President of the Institution for another year. He assured Mr. Johnson, and he assured the Members, that he most heartily regretted that decision, partly on personal grounds, but still more for the sake of the Institution, which both Mr. Johnson and himself desired to serve.

Sir Frederick Bramwell, Bart., Past-President, believed it was his duty to obey the order of their new President, and thereby to set an example to all the younger men present; there were no older men present he thought to whom he could set an example. The order which had been given to him was one that ought to be most gratifying, namely to move a vote of thanks to their retiring President, Mr. Johnson. It would indeed be most gratifying, if he felt competent to fulfil it; but unhappily he did not, having himself had personally so little experience of his guidance of the Institution during the past year, as unfortunately he had himself been laid on the shelf, and for several months his doctor had not suffered him to come near this Institution or any other society; and therefore his personal acquaintance with the work of their ex-President, he was sorry to say, was extremely small. But there were some representations which were spread abroad by common report, of so strong a character and so well set out, that he felt as if he had been present, and he knew they might be taken as true. Having regard to such representations, and to his acquaintance with Mr. Johnson before his presidency, he was perfectly certain he should be only expressing the wishes and meeting with the approbation of all the Members present, in moving that a most hearty vote of thanks be given to Mr. Johnson for the way in which he had conducted the business of the Institution during his year of office. He had heard especially that the visit to Derby had proved all that could be desired, that Mr. Johnson's exertions there had been unremitting, that he was a power in that neighbourhood, and had opened places otherwise secret, and had caused the Institution to receive a most cordial welcome, and that in every way the Summer Meeting held

(Sir Frederick Bramwell, Bart.)

there under his auspices had been a great success. Mr. Johnson had also had much labour in connection with the completion of the building in which they were now assembled for the first time tonight. He did not wish to call his friend Sir William White a cuckoo; but one man had built the nest, and another was come to enjoy it. The labour in connection with the building had been heavy, and it had been carried out, as everything else had been carried out, to the entire satisfaction of the Members. He would therefore move that a most hearty vote of thanks be given to Mr. Johnson, the retiring President, for the efficient manner in which he had in every way carried out his work as President of the Institution.

Sir Edward H. Carbutt, Bart., Past-President, said the seconder of a motion proposed by Sir Frederick Bramwell, who was a past master in making speeches, found everything had been made easy for him, with little need for any effort on his own part. He had himself had the pleasure of knowing Mr. Johnson perhaps longer than any one else in the room, having watched his career from the years when he was himself a young man serving his time on the Midland Railway, and when Mr. Johnson was on the Great Northern Railway at Peterborough. In those early days all the young engineers already looked up to him, and talked about what he was going to do; for even then he had made his mark in the railway world. Since that time, now more than forty years ago, he had been in charge of the locomotive department on several other railways, especially on the Midland Railway for the past quarter of a century. As was well known, he had done everything that could possibly be done to serve the public on the Midland Railway, by making engines which could keep time and could carry the increasing traffic. Sir Frederick Bramwell had alluded to the princely reception accorded to the Members at Derby at the Summer Meeting. No one could have done more in securing such a reception than Mr. Johnson had done; and he felt sure the Members would all wish him long life and prosperity, and thank him for having been the President for one year, only regretting that his modesty had

prevented him from continuing for another year. He had great pleasure in seconding the vote of thanks proposed by Sir Frederick Bramwell.

The resolution was carried with applause.

Mr. Johnson was deeply sensible of the kind eulogies which had come from Sir Frederick Bramwell, and of the warm manner in which the resolution had been seconded by his friend Sir Edward Carbutt. The position which he had held for the last year he had regarded as an exceedingly great honour; personally he did not desire any honour beyond it. If he had in any way contributed, in however small a degree, to maintain the prestige of the presidency and the interests of the Institution, he was amply rewarded. As the Members might know, the duties of the presidential chair were somewhat onerous; and as his presidential year happened to comprise a change of secretary and the finishing of a new building, and several other matters coincident therewith, it had naturally been a time of considerable activity for himself as President of the Institution. He should have been delighted to continue, as the Council desired, for a second year, had he felt that it would be consistent with the many other duties which he had to carry out. He thanked the Members most sincerely for the hearty way in which they had passed the resolution proposed by Sir Frederick Bramwell.

The President reminded the Members that at the present meeting the appointment had to be made of an Auditor for the current year.

Mr. Thomas Ashbury moved:—"That Mr. Robert A. McLean, chartered accountant, 1 Queen Victoria Street, London, be re-appointed to audit the accounts of the Institution for the present year at the same remuneration as last year, namely Twenty-five Guineas."

Mr. John Etherington seconded the motion, which was carried unanimously.

The "Fifth Report to the Alloys Research Committee: Steel;" by SIR WILLIAM C. ROBERTS-AUSTEN, K.C.B., D.C.L., F.R.S., Honorary Life Member, was then read and partly discussed.

Shortly before Ten o'clock the Discussion was adjourned to the following evening. The attendance was 229 Members and 89 Visitors.

The ADJOURNED MEETING was held in the House of the Institution, St. James's Park, London, on Friday, 10th February 1899, at Half-past Seven o'clock p.m.; SIR WILLIAM H. WHITE, K.C.B., LL.D., D.Sc., F.R.S., President, in the chair.

The Discussion upon the "Fifth Report to the Alloys Research Committee: Steel;" by SIR WILLIAM C. ROBERTS-AUSTEN, K.C.B., D.C.L., F.R.S., Honorary Life Member, was resumed and concluded.

The following Paper was then read and discussed:—

"Machinery for Book and General Printing;" by Mr. WILLIAM POWRIE, Member, of London.

The Meeting then terminated shortly before Ten o'clock. The attendance was 124 Members and 91 Visitors.

FIFTH REPORT * TO THE ALLOYS RESEARCH COMMITTEE: STEEL.

BY SIR WILLIAM C. ROBERTS-AUSTEN, K.C.B., D.C.L., F.R.S.,
HONORARY LIFE MEMBER.

Before dealing with the subject to which this Report is devoted, the author would point out that the Research Committees of this Institution exerted a noteworthy influence in connection with the preliminary enquiry, the results of which have led to the recommendation that a National Physical Laboratory should be established. The report of the Council of the Royal Society recently published states that: "The deliberations of the Committee, appointed by Her Majesty's Treasury to consider the desirability of establishing a National Physical Laboratory, have resulted in an important addition to the responsibilities of the Royal Society. The Committee reported in favour of the establishment of such a Laboratory, and recommended that its control should be vested in the Royal Society, who should also nominate its governing body. Her Majesty's Government, having accepted the recommendations of the Committee, has invited the Royal Society to undertake the charge proposed in their report, including the administration of the funds which the Treasury has offered to furnish for the equipment and maintenance of the institution. The Council has decided in general terms to accept the trust offered to the Society." The author was a member of the Treasury Committee to which reference is made; and this Institution was also represented by Professor Kennedy and Mr. W. H. Maw, both of whom, as witnesses before the Committee,

* For the First, Second, Third, and Fourth Reports, *see* Proceedings 1891, page 543; 1893, page 102; 1895, page 238; and 1897, page 31.

gave evidence of a highly important character. It may be added that, in the evidence which was taken by the National Physical Laboratory Committee, frequent reference was made to the work of the Alloys Research Committee. Lord Kelvin, who was also a witness, pointed out that continuing the investigation of alloys in a National Laboratory would be of great importance. The same view was taken in the evidence given by the President of the Institution of Civil Engineers, by the late Sir William Anderson, Professor Oliver Lodge, and several other witnesses. The research work therefore, on which the Committee of this Institution has been so long engaged, is fully and officially recognised, not only as being of national importance, but also as having rendered important service to industry.

Carburized Iron considered as a solution.—In the course of the last Report to the Committee, an attempt was made to connect the freezing-point curves of carburized iron with those of ordinary alloys. The series of Reports as a whole had abundantly shown that alloys behave like saline solutions. It will be evident therefore that, if carburized iron, that is, steel and cast-iron, can be brought into line with ordinary solutions, a point of the utmost metallurgical importance will be gained. The series of results plotted in Plate 11 of the last Report* made it quite clear that the analogy of steel to an ordinary solution of salt is of the closest possible character, even if the evidence rests only on cooling curves taken in the usual way.

Recording Pyrometer.—It was certain however that the question is one of great complexity, and that a far more delicate method than that hitherto in use must be adopted, if conclusive and trustworthy results are to be obtained. The recording pyrometer, which has rendered such good service throughout this enquiry, had therefore to be rendered more sensitive than had hitherto been the case. The improvements described in the last Report consisted, it will be

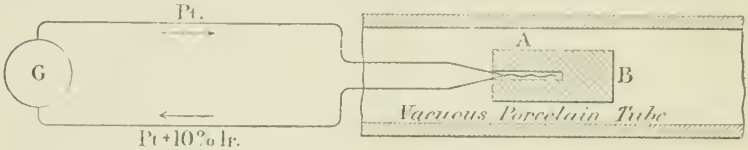
* Proceedings 1897, pages 70 and 90.

remembered, in employing a galvanometer so adjusted that the current produced by heating a thermo-junction attached to it would deflect the mirror through an angle of 50°. The current from the thermo-junction however was not allowed to pass unchecked through the galvanometer. It was opposed by a current from a large Clark cell, and the amount of the latter current could be accurately adjusted and measured by a potentiometer, so that only a small portion of the current from the thermo-junction really passed through the galvanometer. The result is shown in delicate curves, one of which was given in Plate 9 of the last Report (1897). The angular deflection of the galvanometer mirror is small, even at the highest temperatures: the sensitiveness of the instrument is not diminished, its resistance is not increased, but a portion of the current from the thermo-junction is balanced. It was found better to replace the astronomical clock of the older recorder by a water-clock consisting of a float moving upward between guides, and bearing a photographic plate. Since this description was published in 1897, enquiries have from time to time been made as to the details of the appliance. It is therefore shown in Plate 1 of the present Report, which represents that portion of the Research Laboratory where the new recorder is placed. The galvanometers are shown at G and G^1 with sources of light for illuminating their mirrors at L and L^1. The potentiometer is shown at B, and consists of four sets of resistance coils. The current flowing through the potentiometer is maintained by means of a Clark cell *g* with large electrodes. The water-clock H and its float F, the photographic plate P, and the hood K, are shown at the right of the drawing. S is the slit through which the rays of light from the mirrors of the galvanometers G G^1 are admitted to the sensitized plate. The arrangements of the galvanometers are shown diagrammatically in Figs. 1 and 2, page 38; and the system has been described in detail elsewhere * by Dr. Alfred Stansfield, who has assisted in conducting this series of investigations almost from their outset. As the result of many experiments, I adopted the following new method, of which a

* Philosophical Magazine, July 1898, page 59.

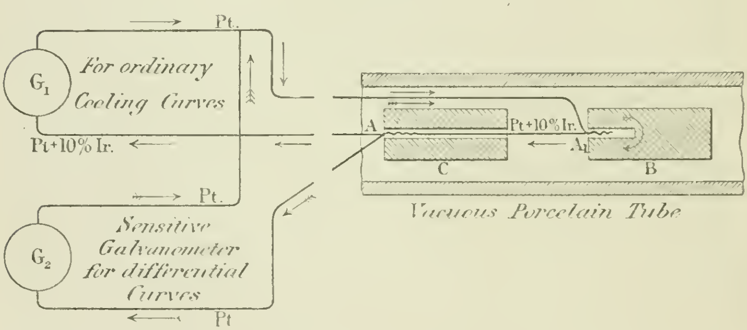
brief description will be sufficient. In the ordinary method, the twisted end of the thermo-junction A, Fig. 1, is placed in the heated mass of

Fig. 1.



metal B under examination, and its free ends are connected with the galvanometer G. In the new method, Fig. 2, two thermo-junctions A and A_1 are employed. One of these is placed in the piece

Fig. 2.



of metal B, and the other in a compensating piece of copper platinum or fire-clay C. A sensitive galvanometer G_2, connected to both thermo-junctions, measures on a large scale the difference between the temperatures of B and C; and magnified records of the evolutions of heat in B can thus be obtained, which are not affected by the general fall of temperature of the system. The actual temperature of the piece of metal B is simultaneously registered by the less sensitive galvanometer G_1 in the usual way. In the new method therefore the heat lost by the cooling mass of metal B, Fig. 2, is compensated or balanced by the heat lost by a mass of platinum C. The result is that the effect on the galvanometer G_2

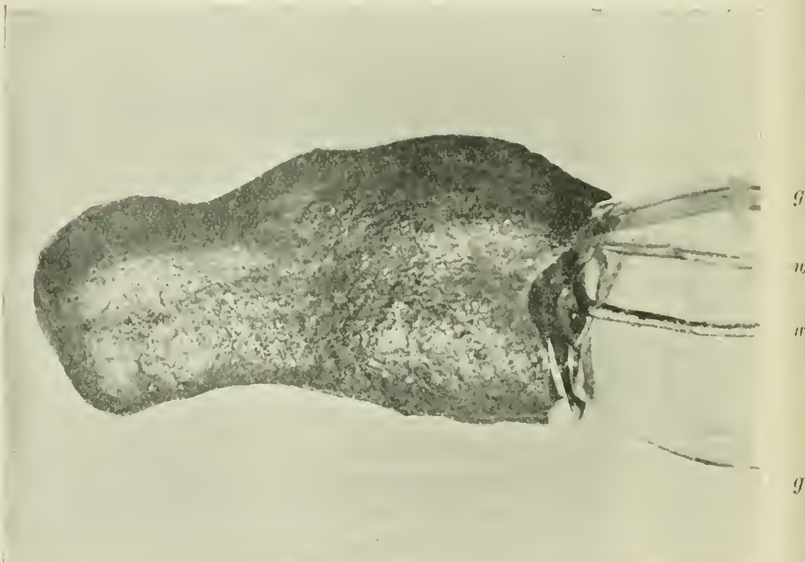
of any evolution of heat by the cooling mass B is greatly augmented. As has already been indicated, the heat suddenly evolved by the mass B of iron or steel, which is liable to molecular change, is not masked by the fact that the mass is itself rapidly losing heat; because the temperature of the entire system does not affect the sensitive galvanometer G_2, and the heat which is evolved by the mass B is free to make itself felt. Hence the curves recorded by the mirror of G_2 possess extraordinary sensitiveness. In Figs. 1 and 2 the arrows show the directions of the currents. Those with feathers indicate the direction of the current which is due to the difference of temperature; this difference is caused by the excess of heat in the iron B, as compared with the platinum C. The featherless arrows show the direction of the current through the unsensitive galvanometer G_1, which records ordinary cooling curves.

Reference to a special case, furnished by the cooling of electro-iron from a white heat, will serve to make this clear. A bead of electro-iron was deposited on a thermo-junction protruding from a glass tube into which the wires were fused. The iron was deposited from a solution of ferrous chloride which had been purified with scrupulous care. The anode was a plate of electro-iron; but the method of preparing the solution and depositing the iron need not be given, as it would break the continuity of this description. The deposited iron weighed five grammes = 0·18 ounce, and its appearance magnified 4 diameters is shown in Fig. 3 (page 40). A transverse section showing one of the wires of the thermo-junction, magnified 50 diameters, is shown in Fig. 4 (page 41). Its hardness was about that of fluor-spar, and when placed in water heated to 70° C. or 158° F. it freely evolved hydrogen, which ceased to come off after some hours. The bead of electro-iron was then arranged as shown in Fig. 2, and was placed in a porcelain tube glazed inside and out, and rendered vacuous by the aid of a mercurial pump, which also enabled the gas evolved from the iron to be collected. More hydrogen was freely evolved as the portion of the tube containing the iron was gradually heated; but, although the evolution of gas never absolutely ceased, the amount of hydrogen

delivered by the mercurial pump was very small when the iron attained a temperature of some 1,300° C. or 2,370° F.

A cooling curve of this iron after four successive heatings is shown in Plate 2, on the actual scale on which it was recorded; and it is at once evident that at least three hitherto unobserved points are

Fig. 3.—*Electro-Iron Bead deposited upon Thermo-junction, magnified 4 diameters.*

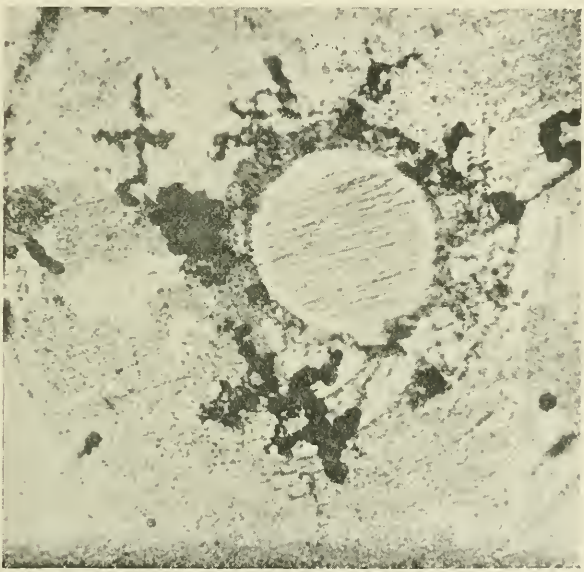


w w = wires of thermo-junction. *g g* = glass.

here revealed. The co-ordinates are time and temperature, as usual; but the temperature represents on a large scale molecular evolutions of heat, and not the temperature of the mass under examination. There is at A the point at 1,132° C. or 2,069° F., which was first observed by my friend and former student, Dr. E. J. Ball. Then at B there is the ordinary Ar 3 of Osmond, which in this case occurs, not as in mild steel at the normal temperature of 850° C. or 1,562° F., but at 895° C. or 1,643° F. When the mass continues to cool down,

there is, as was anticipated, the point Ar 2, which in this case occurs at 766° C. or 1,411° F. The carbon point Ar 1 could not be expected to occur in iron of so high a degree of purity, and it does not exist; but there is evidence of evolution of heat at a point which I believe to be between 550° and 600° C. or 1,020° and 1,110° F. It is difficult to fix this point accurately; it seems to vary somewhat in

Fig. 4.—*Transverse Section of Electro-Iron Bead through Wire of Thermo-junction, magnified* 50 *diameters.*



successive curves. The next point, at which heat evolved, is a new one of extraordinary interest. It occurs between 450° and 500° C. or 840° and 930° F.; and evidence will subsequently be adduced to show that it is connected with the retention of hydrogen by the mass of iron, even though it had been heated to 1,300° C. or 2,370° F. Finally there is a small evolution of heat at about 261° C. or 502° F., that is, at a temperature of no less than 400° C. or 720° F. below redness. The significance of these new points will now be considered.

Iron and Hydrogen.—It will first be desirable to give a brief summary of what is known as to the relations of hydrogen and iron. The late Professor Graham proved, so long ago as 1866, not only that hydrogen would freely penetrate tubes of iron at a red heat, but also that iron would, in cooling from redness in an atmosphere of hydrogen, occlude about 0·46 of its volume of the gas.* Later Cailletet † decomposed electrolytically a solution of ferrous chloride rendered neutral by the addition of ammonia, and obtained brilliant crystals of iron, which were sufficiently hard to scratch glass, and contained 0·028 per cent. of hydrogen. Johnson, Hughes, Baedeker, Ledebur, have all recorded ‡ the fact that, when iron is attacked by dilute sulphuric or hydrochloric acid, it retains hydrogen.

My own experience, extending from the year 1870, when the late M. H. de Jacobi, of St. Petersburg, first taught me the method of depositing electro-iron, is to the effect that, although iron electrolytically deposited may scratch glass, it is not always deposited in the hard form ; and this fact is generally known. I have elsewhere § shown that the iron as deposited breaks with a tension of 2·7 tons per square inch, but that annealing at 800° C. or 1,470° F. raises the tenacity to 15·5 tons per square inch.

The experiments of Müller, which have been confirmed by Stead, on the gases released from ingots of iron and steel by drilling them, show the vast importance of the relations subsisting between iron and steel and the gases they occlude. It is strange however that, although in the Bessemer converter torrents of air charged with a comparatively small amount of aqueous vapour pass through the molten metal, the hydrogen is retained by the solid metal in far greater proportion than either the nitrogen or the carbonic oxide.

* Graham, Collected Works, page 279.

† Comptes Rendus, vol. lxxx, page 319.

‡ Johnson, Proceedings of the Royal Society, vol. xxiii, 1875, page 168; Hughes, Journal of the Society of Telegraph Engineers, 1880, page 163; Baedeker, Zeitschrift des Vereines deutscher Ingenieure, 1888, page 186; Ledebur, Stahl und Eisen, 1887, page 681 ; 1889, page 745.

§ Journal of the Iron and Steel Institute, 1887, No. I, page 71.

We have yet to take into account the amount of argon which passes through the metal in the course of an ordinary Bessemer blow.

In connection with the occlusion of gases in pig-iron, steel, and wrought-iron, the excellent work of Parry must be especially mentioned, in which he showed how persistently iron retains hydrogen.* Professor Arnold pointed out † in 1893 that in fused wrought-iron and in Swedish iron the point Ar 3 of recalescence occurs "much more sharply between narrower limits of temperature" when hydrogen and other occluded gases are removed.

The present investigation places the relations of iron and hydrogen in a new light. As already stated, the cooling curve given in Plate 2 shows the existence of two distinct evolutions of heat, which occur at about 487° and 261° C., or 908° and 502° F. These points in the cooling curve were recorded after the electro-iron had been heated in vacuo to 1,300° C. or 2,370° F. three successive times; but after repeated heatings of the metal in vacuo they become so small that it is impossible to identify them with certainty. There would therefore seem to be but little doubt that they are due to the presence of hydrogen occluded in the iron. The upper point at 487° C. or 908° F. may represent the separation of a hydride of iron from solid solution in the mass of iron; and the lower point at 261° C. or 502° F. may be the corresponding eutectic point.

It is remarkable that repeated heatings and coolings of low-carbon and electro-deposited iron in vacuo reduce the magnitude of all the now well-known molecular changes—Ar 1, Ar 2, Ar 3—as indicated on the cooling curves. The exhausted electro-iron may be re-charged with electrolytic hydrogen, by making it the negative electrode of a battery decomposing acidulated water. If the re-charged iron be heated in vacuo as already described, it will be found that the evolutions of heat in cooling, and consequently the points on the curves, will be restored to their original magnitude. As regards the two new hydrogen points, the upper one at about 487° C. or 908° F. is partially restored by re-charging the iron with electrolytic hydrogen,

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* Journal of the Iron and Steel Institute, 1873, No. I, page 429; and 1874, No. I, page 92; and 1881, No. I, page 183.

† Second Report, Proceedings 1893, page 159.

but the lower point at 261° C. or 502° F. is not. These results, which suggest that the molecular changes in iron are dependent upon, or are influenced by, the presence of small quantities of hydrogen, demand most careful study. Some experiments which I have still in progress show that the relations between hydrogen and iron are far more complicated than they have hitherto been supposed to be.

Carburized Iron considered as a Solid Solution.—The provision of this new and highly sensitive method of recording made it possible to resume that part of the investigation relating to the study of carburized iron, considered as a solid solution, the nature of which was briefly indicated in the last Report. It was therein stated that the curves shown in Plate 11 of that Report (1897) were the freezing-point curves of carburized iron, and served to show that this metal might be brought into line with ordinary saline solutions. It was also pointed out that such curves had been obtained quite independently in France by M. Osmond * so long ago as 1888, and more recently by M. Henri le Chatelier and by myself. The curves shown in Plate 11 (1897) constituted however the first attempt to embody in curves a comprehensive series of results. Since that Report was issued, the importance and urgency of the work have become more and more evident. The solution theory of iron and steel has formed the subject of an elaborate memoir, which was communicated to the Iron and Steel Institute by Baron Hanns von Jüptner, of Neuberg, Austria, in May last, and continued at the Autumn Meeting of the Institute. He pointed out that the data contained in Plate 11, just referred to, are far more conclusive than those which he himself had had at his disposal, "and allow of the hope of considerably enlarging our point of view, and of correcting our earlier conclusions in many respects." †

The constitution of salt solutions was studied by Guthrie so long ago as 1876; and his actual results ‡ for solutions of common salt in

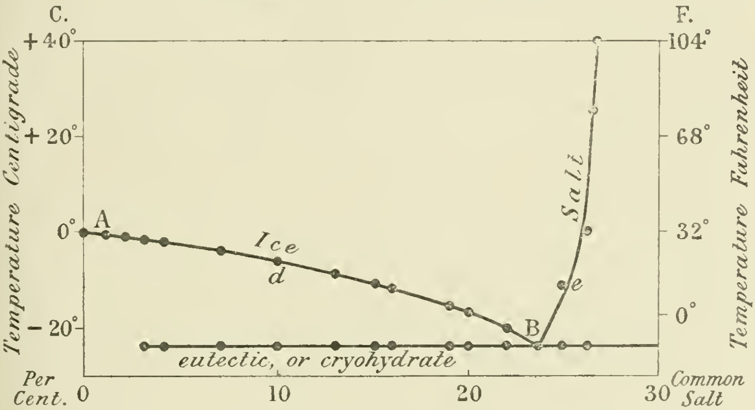
* Annales des Mines, vol. xiv, 1888, pages 39 and 59.

† Journal of the Iron and Steel Institute, No. II, 1898, page 243.

‡ Guthrie, Philosophical Magazine, vol. i, 1876, page 359.

water are given in Fig. 5, in preference to the diagrammatic form by which they are sometimes represented. In order to render clear the nature of the curve given in the diagram, Plate 4, reference must be made to what happens when an ordinary solution of common salt in water is frozen. Fig. 5 shows how a thermometer plunged in the solution falls as the solution cools down. The dots along the lines are points of halt in the mercurial column; it is seen that in most cases there are two points for each stage of concentration.

Fig. 5. *Freezing-point Curves of solution of Common Salt in Water.*



The diagram consists of two branches, the one marked "ice," and the other "salt." It will be best explained by taking two solutions containing two definite amounts of salt on either side of the point B where the branches meet. If, for instance, a thermometer be placed in a solution of 10 per cent. of salt in water which is being slowly cooled down by means of an external freezing mixture, the mercury will halt in its fall at about −8° C. or 18° F.; this is due to the separation of pure salt-free ice. This gives the point *d* on the branch A B. The mercury then continues to fall until the temperature of −22° C. or − 8° F. is reached, and the cryo-hydrate or eutectic of ice and salt solidifies. This eutectic, as has been abundantly shown, consists merely of crystals of ice and of salt in juxtaposition. As the degree of concentration of salt in the

original solution increases, the initial freezing point on the branch A B will be lower and lower, while the second freezing point always remains constant at $-22°$ C. or $-8°$ F.; and when the solution contains 23·5 per cent. of salt, both freezing points coincide in the point B at $-22°$ C. or $-8°$ F.

The salt branch of the diagram is a very steep one, because the melting point of pure salt is above 700° C. or 1,300° F. Take on this branch a point *e*, representing water containing more salt than 23·5 per cent., say 25 per cent. In this case the first solid to separate on cooling is pure salt, and it does so at $-12°$ C. or 10° F., which, for this degree of concentration of salt, is the first halting stage of the thermometer: the second is, as before, the solidification of the eutectic of salt and ice, which always has the same composition, and freezes at the same temperature, namely $-22°$ C. or $-8°$ F. The diagram therefore has two branches joining at B a horizontal line.

Carbon-Iron Solution.—The case of carburized iron is just the same, and is shown in the diagram, Plate 4. In conducting an investigation of this kind, it is most difficult to obtain a series of carburized irons in which the variation in the amount of carbon is progressive, while the amounts of other elements present in the iron either are maintained approximately constant, or vary only in a definite way. I have therefore much pleasure in expressing the great indebtedness of the Committee to Mr. John H. Darby of the Brymbo Steel Works, Wrexham, who most kindly prepared for me a series of small ingots of samples of metal which were successively ladled and cast at intervals of thirty minutes, during the working of a large hæmatite charge in a basic-lined Siemens furnace. These small ingots were analysed for me by Mr. F. W. Harbord, of the Royal Indian Engineering College, Cooper's Hill; his well-known skill as an analyst enables me to place the utmost confidence in the accuracy of the results, and my grateful thanks are due to him. These results are embodied in Table 11. I deliberately adopted a series that was not free from manganese, because a sufficient number of other samples of carburized iron had been prepared for comparison.

TABLE 11.

Chemical Analyses of Steel Samples taken at intervals of 30 minutes, during the working of a Hæmatite charge in a Basic Siemens Furnace, producing low-carbon steel. Brymbo Steel Works, Wrexham.

† *See Plates 8 to 11.* †

Nos.	Carbon.	Silicon.	Sulphur.	Phosphorus.	Manganese.	Arsenic.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
† 1	1·800	0·008	0·032	0·054	0·391	trace
2*	—	—	—	—	—	—
3	1·740	0·006	0·037	0·046	0·380	trace
4	1·451	0·006	0·029	0·023	0·310	0·004
† 5	1·461	0·007	0·038	0·025	0·340	0·002
6	1·234	trace	0·030	0·013	0·327	0·004
† 7	1·161	do.	0·030	0·016	0·290	trace
† 8	0·927	do.	0·025	0·013	0·293	0·004
9	0·912	do.	0·036	0·010	0·236	trace
† 10	0·821	do.	0·040	0·008	0·270	0·002
† 11	0·690	do.	0·038	0·009	0·220	0·004
† 12	0·540	do.	0·032	0·006	0·280	trace
13	0·434	do.	0·030	0·009	0·270	do.
† 14	0·342	do.	0·032	0·006	0·270	0·003
15	0·160	do.	0·037	0·008	0·240	trace
16	0·145	do.	0·041	0·006	0·250	do.
17	0·102	do.	0·037	0·008	0·230	do.
18*	—	—	—	—	—	—
19	0·070	trace	0·035	0·008	0·244	trace
20*	—	—	—	—	—	—
† 21	0·097	trace	0·030	0·007	0·220	0·004
22*	—	—	—	—	—	—
23	0·108	trace	0·033	0·005	0·240	trace
24	0·101	do.	0·034	0·004	0·217	do.
25	0·078	do.	0·033	0·007	0·217	do.

* Nos. 2, 18, 20, and 22 were not analysed.

In the curve now presented to the Institution in Plate 4, in which the letters and general form are the same as in Plate 11 of the fourth Report (1897), an attempt is made to represent the constitution of carburized iron so far as it is at present known. The curve has two main branches A B and B D, meeting at B in the horizontal line *a c*. The line A B corresponds with the separation of pure ice in the diagram, Fig. 5 (page 45), while the line B D corresponds with the separation of salt. In the iron-carbon diagram the line A B indicates the "freezing" of iron, while the line B D denotes the separation of graphite. There is this difference however between the ice and the iron; the latter, on account of the high temperature at which it melts, still retains a certain amount of carbon after it has become solid. Hence there is a *solid* solution of iron and carbon, and this introduces further complications when the iron has cooled to a temperature at which it is no longer capable of retaining dissolved carbon.

First as regards electro-iron, which possesses a high degree of purity, suppose it to be in fusion, and well above its melting point. As the liquid mass cools down, it solidifies; and the point of solidification may be taken to be about 1,600° C. or 2,900° F., although this has not been determined with accuracy. When the iron has become solid, it exists in a plastic state, to which the name of γ iron has been given by Osmond; and while it is in this state it is capable of dissolving between 0·8 and 0·9 per cent. of carbon at 700° C. or 1,300° F., and rather more at higher temperatures; at 1,000° C. or 1,800° F., for instance, it would dissolve about 1·5 per cent. of carbon. It must be borne in mind however that the solubility of a substance depends on the form in which it is presented to the solvent; thus carbon in the form of ordinary graphite has a much lower degree of solubility at certain temperatures than carbon in the combined form known as "cementite." This suggests a reason why steel contains more combined carbon than slowly cooled pig-iron.

As pig-iron cools down, graphite falls out of solution when the temperature of the eutectic *a c* is reached: that is, the liquid eutectic of carbon and iron solidifies along the line *a c*. The amount of graphite, in any variety of pig-iron which contains up to about

4 per cent. of carbon, will be indicated by the amount of heat evolved at this temperature, namely 1,120° C. or 2,048° F. In pig-irons containing more than 4 per cent. of carbon, an increasing amount of graphite appears on the upper branch B D. The "combined carbon" is mainly the carbon retained by the iron which solidifies on the line A B, though of course the iron which solidifies on the eutectic line *a c* also retains some carbon.

In Plate 4 are added three hypothetical lines, B*y*, *yv*, and *xyz*. B*y* shows the possible separation and solidification of iron in white iron, and is a continuation of the line AB; *yv* represents the possible separation of cementite in fused white iron; while the horizontal line *xyz* indicates the possible position of the solidification of the iron-cementite eutectic in white iron. This important addition to the curve was suggested to me by Professor Henri le Chatelier, to whom my best acknowledgments are due.

Changes in Solidified Carburized Iron.—The changes which have hitherto been considered relate to the solidification of either carbon-free (electro) iron or carburized iron. In all that follows, changes in *solid* carburized iron are alone considered.

When pure γ iron cools to the point G in the diagram, Plate 5—namely 890° C. or 1,634° F., or Ar 3—it undergoes a change to β iron, and the change is attended with an evolution of a considerable amount of heat. Like γ iron, β iron is non-magnetic, but it is much less capable of holding carbon in solid solution than γ iron. As the iron cools down to the point M—namely 770° C. or 1,418° F., or Ar 2—a further change takes place to α iron, which is magnetic. Much heat is evolved at Ar 2, but less suddenly than at Ar 3 (890° C. or 1,634° F.), probably because the iron is less mobile at the lower temperature (770° C. or 1,418 F.). As β iron dissolves less than 0·1 per cent. of carbon, the influence of carbon upon iron is practically eliminated at temperatures below the point G of the change to β iron. For this reason the line M O must be horizontal, as in the later work it has been found to be.

Iron containing about 0·2 per cent. of carbon may next be considered. It solidifies at a temperature a little lower than the

melting point of pure iron, and the whole of the carbon remains in solution in the solid γ iron. There is therefore no liquid carbon-iron eutectic present to solidify at 1,120° C. or 2,048° F. When the iron containing about 0·2 per cent. of carbon cools still further, the evolution of heat known as Ar 3 occurs at about 830° C. or 1,526° F. The Ar 3 point has been lowered by the presence of carbon, in the same way that the freezing point of water is lowered by the addition of salt; and, just as in the salt solution, pure iron, which corresponds with ice, crystallises out, and the temperature continues to fall until at a definite temperature the whole of the still liquid solution solidifies. Thus, in the solid solution of 0·2 per cent. of carbon in γ iron, pure iron separates out of the solution and crystallises as β iron, forming ferrite. The temperature still continues to fall, until at about 690° C. or 1,274° F. the rest of the solution is broken up, forming pearlite. The iron changes from γ to β and then to α iron, while the carbon separates as cementite, Fe_3C. This separation of the carbon as a compound is analogous to the separation of copper sulphate from a solution, as the salt retains a definite amount of water of crystallisation.

Meanwhile the iron which separated as β iron at 830° C. or 1,526° F. has undergone another change to α iron at 770° C. or 1,418° F., the Ar 2 point. As β iron is free from carbon, the temperature of its change to α iron (Ar 2) is unaffected by the carbon contents of the steel as a whole.

In steel containing 0·6 per cent. of carbon the Ar 3 point has become depressed to about 720° C. or 1,328° F., so that all the iron remains in the γ form; when however this temperature is reached, pure iron or ferrite separates out, changing from the γ to the β and immediately to the α form. The rest of the iron remains in solution with the carbon until about 690° C. or 1,274° F. is reached.

The hypothetical lines EK and KL in Plate 5 indicate the separation respectively of cementite and of ferrite from a solid solution of highly carburized iron. If there is less carbon than 4·25 per cent., cementite will separate; but if there is more, ferrite separates.

The sensitive method already described of recording the cooling curves has revealed the existence of a new point at which heat is evolved as iron cools down. This point occurs at about 600° C. or 1,100° F.; it may be premature to give it a definite symbol, but adopting M. Osmond's scheme of nomenclature it would be Ar 0. It appears to be the beginning of a comparatively slight molecular change which is not completed suddenly, but occurs over a range of 100° C. or 180° F. This change is also accompanied by a change in magnetic properties, for at this temperature of 600° C. or 1,100° F. Dr. D. K. Morris * has already decided a change in the permeability of iron. In Plate 3 are shown four of these delicate differential cooling curves from samples of steel containing severally 0·540, 0·342, 0·160, and 0·102 per cent. of carbon.

Mechanical Properties of Carburized Iron considered in relation to the Solubility (or Freezing-point) curves.—In the last Report † it was shown that it is possible to trace the relation between the freezing-point curve of the brasses and the curves which represent their mechanical properties of tenacity and extensibility. In the diagrams, Plates 4 and 5, the abscissae show the percentages of carbon for all the curves, while the ordinates represent temperatures. If a vertical scale of tensile strength were attached to Plate 5, and a curve of tensile strengths of annealed steel were to be plotted, it would be found that the point of maximum strength coincided very closely with the solid eutectic of iron and carbide which corresponds with 0·9 per cent. of carbon. The tenacity and freezing-point curves are directly and closely related; but Plates 4 and 5 are already so full that it is considered undesirable to plot the tenacity curve thereon in addition.

At the outset a grave difficulty is presented; the effect of varying amounts of carbon on the tenacity and extensibility of pure iron is not as yet known: that is, the presence of other elements intervenes and complicates the effect produced by carbon. It is only necessary

* Philosophical Magazine, part II, 1897, page 213, and Plates on pages 250-1.
† Fourth Report, Proceedings 1897, page 43.

to glance at such a Table as that given in the classical work of Professor Howe * in order to see with what great difficulties the question is beset. Professor Howe gives the limits within which the tenacity of iron containing from 0·05 to 1·30 per cent. of carbon probably varies. The degree of carburization corresponding with the greatest strength is of the utmost importance, and fortunately the investigations of Professor Arnold are available. He had studied the effect of carbon on iron of a high degree of purity; and a "bent lath" curve, passing through all the points he gives for the series of annealed steels, fixes the maximum tensile strength at about 0·9 per cent. of carbon, which is very close to the composition of the eutectic 0·89 per cent. of carbon. Professor Arnold's value for these critical points in the curve of tenacity may safely be adopted for annealed steels; but, as he points out, the same series of steels in the "normal" state as received from the rolls give considerably higher results, and in these the point of maximum tensile strength occurs in steel containing 1·2 per cent. of carbon.

In the brasses (Plate 3 of the fourth Report, 1897) the point of maximum tensile strength occurs in the alloy which has a single solidifying point. In the same way, in the carbon-iron series the point of maximum tensile strength occurs in the alloy which in cooling has all the heat evolved at a single point. In the carbon-iron series it is not, as it is in the brasses, the *initial* freezing point which determines the strength, but the arrangement of the mass long after it has become solid, that is, when it is in *the form of solid solution.*

Evidence afforded by the Microscope.—If carburized iron is a solution capable of being either liquid or "frozen," it might be anticipated that the constituents of the solid solutions would be recognizable by the microscope, just as individual crystallized salts grouped together can be distinguished by suitable magnification. Patient research conducted with the aid of the microscope, beginning with the work of Sorby in 1864, has during the last thirty-five years proved that this is the case. Professor Arnold also has

* "Metallurgy of Steel," page 14. New York, 1890.

recently published some beautiful coloured drawings illustrating the micro-chemistry of cementation.*

Carburized Iron considered as a Solution.—It has been already pointed out that a frozen solution of ice and salt consists of two constituents, either *ice* and *eutectic*, or *salt* and *eutectic*. Whether ice or salt separate will depend on the degree of concentration of the saline solution. In the same way solidified solutions of iron carbide and iron are also composed of either *iron* and *eutectic*, or *iron carbide* (Fe_3C) and *eutectic*, according to the amount of carbide present. It has been shown that all eutectics are finely divided mechanical mixtures, and Osmond has pointed out that the iron and iron-carbide eutectics are no exception.

It will be well to consider how the question of solution bears upon the constitution of carburized iron in common use. In order to do this the evidence of the microscope is all important. Micrographic methods have been so often described † that it is unnecessary to dwell upon them further than to state that, when highly polished surfaces of steel are treated with certain re-agents, some of the constituents, the carbides, become stained, while the iron retains its original colour.

For micrographic purposes, steel is viewed as if it were a rock with various minerals distributed through it, and mineralogical names are conveniently adopted for the constituents. Thus, iron free from carbon is called "Ferrite," which is left white and brilliant when the polished specimen is treated with either a very dilute solution of nitric acid or an infusion of liquorice. Strong nitric acid does not attack the ferrite; but this re-agent should not be used without great care. Very dilute solutions of nitric acid either in alcohol or in water develop the crystalline structure of the ferrite, as is shown in Figs. 11 and 12, Plate 6. Nitric acid etching however impairs the sharpness of the pearlite, and tends to produce porosity.

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* Journal of the Iron and Steel Institute, 1898, No. II, page 185.

† Roberts-Austen, "Introduction to the Study of Metallurgy," 1898, page 391, where a bibliography is given.

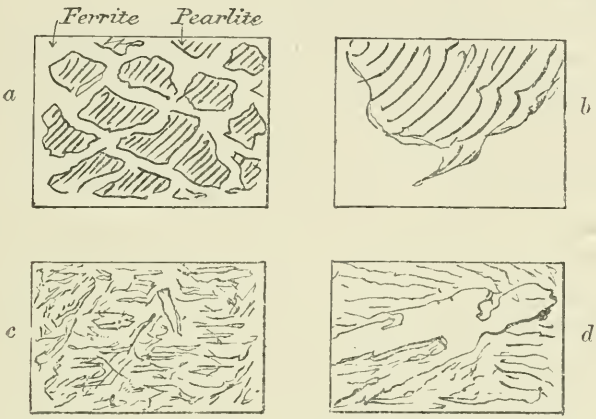
"Cementite," another constituent of steel, is a carbide which corresponds with the formula Fe_3C. It remains bright after the polished section of steel is attacked by either iodine solution or an infusion of liquorice. It is hard, and stands in relief when the steel is polished with the finest rouge on parchment placed on a soft support, such as wood. Free "cementite" however occurs very rarely in low-carbon steel. The carbide in low-carbon steel usually assumes the form of "Pearlite," which is an intimate mixture of ferrite and cementite. It is a characteristic constituent of steel which has been slowly cooled from a high temperature; and if the steel contains about 0·9 per cent. of carbon, the mass will consist entirely of pearlite. It may be either lamellar or granular in structure. It may be coloured dark by iodine solution; and its presence is best revealed when the steel is polished in relief by the method which has just been indicated, and treated with a filtered infusion of liquorice root in cold water. It consists of lamellae, which are alternately hard and soft. Hardened steel appears to be composed of "Martensite," a system of interlacing crystalline fibres, which may readily be coloured by a tincture of iodine. Photographs of these various constituents will be referred to immediately. In all cases the illumination was vertical, and with three exceptions the sections were stained with an infusion of liquorice root. (*See description of Plates, pages* 55–59.)

In order to make clearer the nature of these main constituents of carburized iron, photo-micrographs may be directly appealed to. Pure iron or "ferrite," like pure ice, exhibits crystalline planes. But if only a minute proportion of carbon be present, even so little as 0·04 per cent., there may be, as Stead has shown, in such iron which has cooled slowly, evidence of carbide of iron as a cement between the grains. Such a section of iron, etched with 1 per cent. of nitric acid in alcohol, and magnified 140 diameters, is shown in Fig. 11, Plate 6.

In slowly cooled iron, which contains from 0·3 to 0·5 per cent. of carbon, the carbide will be concentrated into patches of pearlite set in ferrite, as is shown in the accompanying sketch *a*, Fig. 6, or in Fig. 13, Plate 6. Very high magnification, such as 1,000 diameters,

resolves these patches of pearlite into banded structures consisting of alternate laminae of hard carbide and soft ferrite, as shown in sketch *b*, Fig. 6, or in Fig. 15, Plate 6; the mass as a whole is called pearlite from its resemblance to "mother of pearl."

Fig. 6.



Martensite entirely. *Cementite patch in centre.*

Approximate magnifications:—

$a = 200$; $b = 1{,}000$; $c = 800$; $d = 800$ diameters.

Iron becomes saturated when the proportion of combined carbon is about 0·9 per cent.; and if such a metal has been slowly cooled, it will consist entirely of pearlite without any free ferrite, as shown in Fig. 15, Plate 6; while if the proportion of carbon exceeds 0·9 per cent., the carbide layers will show a tendency to run together into bands of cementite, which is shown white in *d*, Fig. 6, and light in Fig. 16, Plate 6. When a low-carbon steel contains much manganese, the area of the pearlite becomes large relatively to that of the ferrite, and the grains also increase in size. This is well shown in Fig. 14, Plate 6, which represents steel containing approximately the same percentage of carbon as Fig. 13, but considerably more manganese. When examined under a high power, the structure of the grain of pearlite in steel containing much manganese is almost invariably more minute than in steel containing but little of that metal.

The appearance of carburized iron after rapid cooling, as in the operation of hardening steel, is widely different. A constituent known as "Martensite" appears; its general nature is shown in the sketch *c* (page 55), or in Fig. 19, Plate 7, which represents steel containing 0·51 per cent. of carbon after quenching in water from a temperature of 1,000° C. or 1,832° F. The "tempered" structure of such a steel somewhat resembles the last figure, and is shown in Fig. 20, Plate 7. If the proportion of carbon be still higher, say 1·5 per cent., and if the cooling be rapidly effected in iced brine, another constituent appears, which may be scratched with a hard needle, and to which M. Osmond, who discovered it, has given the name of "Austenite." Its general appearance is shown white in Fig. 22, Plate 7, magnified 850 diameters. By the great kindness of Professor Dewar I have been permitted to quench a high-carbon steel, heated to 1,000° C. or 1,832° F., in liquid air, the temperature of which is – 200° C. or – 328° F. The result is shown in Fig. 21, Plate 7, magnified 60 diameters; but, notwithstanding the extreme cold, the structure of the steel does not materially differ from that which would have been produced by allowing the metal to cool rapidly under ordinary atmospheric conditions, probably because a vaporized layer of air instantly forms and prevents the liquid air from coming in contact with the hot steel. Other constituents are called "Troostite" and "Sorbite"; they are modifications of cementite, but their consideration is beyond the limits of the present Report, though an example of Troostite is shown black in Fig. 18, Plate 7. Troostite is produced by quenching steel up to 0·4 per cent. of carbon at about 750° C. or 1,382 F°. Slag flaws which occur in steel and iron vary in appearance with their composition. In Fig. 17, Plate 7, is given a fairly typical slag-flaw, magnified 640 diameters; it occurred in a rail which broke on the road in India. The rail had previously withstood the mechanical tests well; and chemical analysis showed that it contained about 0·27 per cent. carbon and 0·71 per cent. manganese, the other constituents being present in very small quantities.

So far, only typical modes of occurrence have been considered; and specific cases may now be dealt with. For photo-micrographs a series has been selected either of cementation steels prepared in the

laboratory or of the Brymbo series, the composition of which is given in Table 11 (page 47). The iron which formed the basis of the cementation series is given in Figs. 23 and 24, Plate 8. They show nearly carbon-free iron, containing only 0·07 per cent. of carbon, magnified 140 and 850 diameters. In Fig. 23 there are a few small patches of pearlite, which under the higher magnification in Fig. 24 reveal their true pearlite structure. Figs. 25 and 26 show one of the specimens lowest in carbon of the Brymbo series (Table 11, No. 21, page 47). The specimen contains 0·097 per cent. of carbon, and contains small patches of pearlite in a matrix of crystalline ferrite. As in the preceding case, these patches reveal a true pearlite structure under the higher magnification in Fig. 26. The above specimens, Figs. 23 to 26, were etched with alcohol containing 1 per cent. of nitric acid.

Figs. 27 and 28 show the effect of carburizing the iron given in Figs. 23 and 24. It will be seen that the structure is very different from that found in the rail steels, of which typical examples are given in Plates 14 and 15. Here the grains are nearly elliptical or circular, no trace being visible of the interlocking grains. The higher magnification in Fig. 28 shows fairly typical pearlite; but the laminæ are by no means so well formed as in some of the other specimens.

Figs. 29 and 30, Plate 9, also represent a preparation of cementation steel made in the laboratory. The grains in this are very small, in fact smaller than any other grains of the series, and have a more or less rounded shape. The higher power in Fig. 30 reveals good bold pearlite with well-developed laminæ. This specimen contains 0·3 per cent. of carbon. Figs. 31 and 32 show the structure of one of the Brymbo series (Table 11, No. 14, page 47), which is of similar composition to the last cementation steel, and contained 0·342 per cent. of carbon. The grains are rather larger than those of the last specimen, and the pearlite under higher magnification in Fig. 32 proved to be equally well formed. Figs. 33 and 34 show similar magnified sections of Brymbo steel No. 12, containing 0·54 per cent. of carbon. The grains are more angular than any yet seen in this series of steels; but none have been subjected to any mechanical

treatment which would have caused the grains to interlock. The pearlite is quite typical of what should occur in pure steel containing this percentage of carbon.

Fig. 35, Plate 10, shows Brymbo steel No. 11, containing 0·69 per cent. of carbon, magnified 140 diameters. The grain here also is small. Fig. 36 is a cementation steel containing 0·552 per cent. of carbon, magnified 850 diameters. The pearlite is broad and well developed. The portion shown in the photograph is not quite typical, considering the amount of carbon, although in other portions of the specimen the ratio of ferrite to pearlite is much greater. Fig. 37 is a low power (140 diameters) of Brymbo No. 10, containing 0·821 per cent. of carbon. There is a certain amount of ferrite visible in the mass. Fig. 38 is a variety of steel of almost exactly the same composition as Brymbo No. 10, and has been subjected to the same thermal treatment; as will be seen, magnification of 850 diameters shows that nearly the whole mass consists of pearlite. Its carburization is close to the saturation point of carbon in iron. Figs. 39 and 40 are respectively low and high magnifications of Brymbo No. 8, which contains 0·927 per cent. of carbon. The lower power in Fig. 39 shows a more or less confused mass containing patches of cementite. When magnified 850 diameters in Fig. 40, the confused mass resolves itself into pearlite. In no part of the field does the cementite encircle the grains of pearlite.

Figs. 41 and 42, Plate 11, are preparations from Brymbo No. 7, containing 1·161 per cent. of carbon, and show very similar structures to the last; but much more cementite is present. Figs. 43 and 44 were prepared from Brymbo No. 5, containing 1·461 per cent. of carbon; unlike the two previous specimens, the cementite here completely surrounds the grains of pearlite, and might easily under a low power be mistaken for ferrite. The photograph at first sight is not unlike a highly manganiferous rail-steel, containing say 1·0 per cent. of manganese and 0·4 per cent. of carbon. Careful examination under the microscope shows that the cementite appears in relief, and has a high polish and must therefore be hard. Under a magnification of 850 diameters in Fig. 44 quite a different appearance presents itself; the material surrounding the grains in

Fig. 43 is found to be disconnected, in fact made up of irregular patches, and not continuous as it would have been had it been ferrite. As seen in the photograph, this constituent exhibits all the characteristics of cementite. Figs. 45 and 46 show Brymbo No. 1, containing 1·8 per cent. of carbon. These photographs reveal all the peculiar characteristics of the previous specimen (Figs. 43 and 44), with the exception that the ratio of pearlite to cementite is much greater in Figs. 45 and 46, owing to the higher percentage of carbon.

Plate 12 is devoted to pure cast-irons under a magnification of 850 diameters. Fig. 47 is a white iron, containing 2·573 per cent. of combined and 0·190 per cent. of graphitic carbon; the structure is almost entirely made up of cementite and pearlite. Fig. 48 shows a grey cast-iron, containing 1·124 per cent. of combined and 2·640 per cent. of graphitic carbon; here the matrix is mainly composed of pearlite, with patches of cementite and graphite. Fig. 49 is a grey cast-iron prepared in the electric furnace; it contains about 4·02 per cent. of carbon, and is composed of cementite, graphite, and pearlite. Fig. 50 is also a grey cast-iron prepared in the electric furnace; this specimen is much softer than that shown in Fig. 49, the cementite in Fig. 49 being here replaced by ferrite, which contains a large number of minute octahedra; these stand in relief, and have all the appearance of small crystals of diamonds. Fig. 51 is another specimen of grey cast-iron prepared in the electric furnace; it shows a structure of which the matrix is composed of well-developed pearlite; the matrix contains a number of grains of ferrite and graphite, and the outlines of many of the graphite grains are much curved. Fig. 52 is a specimen of grey cast-iron, which has been carburized as highly as possible in the electric furnace; it contains about 5·2 per cent. of carbon, and is composed of ferrite, pearlite, and a large amount of graphite; the button of metal after carburization was very soft, and pieces were easily reduced to powder under the hammer.

The bearing of these considerations on industrial practice will now be dealt with. In iron containing 0·2 per cent. of carbon, which is being cooled slowly, the evolution of heat at 830° C. or 1,526° F. represents the formation of the pure ice of the

iron-carbon series, or as it is called "ferrite." This pure iron undergoes a further molecular change on cooling down to 770° C. or 1,418° F., when it becomes magnetic. The formation of the pearlite shown in the diagram is indicated by the halt at about 690° C. or 1,274° F.

Among the carburized irons which are comparatively low in carbon, few members of the series are more important than those which lie between the points O and S in the diagram, Plate 5. They are widely used for steel rails, and contain from 0·3 to 0·8 per cent. of carbon. It is remarkable that the complexity of constitution indicated by the curves in Plate 5 is considerably lessened in this class of steel. In the cooling curve of a rail steel there are only two points of halt: the first, occurring between 700° and 750° C. or 1,300° and 1,380° F., represents both the separation of ferrite and the magnetic change; while the second halt, occurring at about 690° C. or 1,274° F., indicates the separation of the carbide "pearlite."

Application of Photo-micrography to the study of Steel Rails.—A preliminary treatment of an entire cross-section of a rail by dilute sulphuric acid affords much information as to the exact positions of the portions which it is desirable to subject to detailed examination. A transverse section about one inch in thickness is cut from a rail; one face is then carefully surfaced, and the back and edges of the section are covered with a suitable protecting varnish. The section is then placed with its unprotected surface upwards in a bath of dilute sulphuric acid (4 water to 1 acid) raised to a temperature of 60° C. or 140° F. The action of the acid is maintained for two hours, when the section is removed, washed in warm water, and dried. The appearance of the specimen is much improved by dipping the prepared surface in concentrated nitric acid, washing in water, and drying. It is probable that the whitish stains, which after the first treatment generally adhere to such a prepared surface of a rail section and impair its appearance for photographic purposes, are composed of carbide Fe_3C, which has not been dissolved by the sulphuric acid. This Fe_3C is rapidly dissolved by the nitric acid

followed by washing, and a clean surface is left. The result of such preliminary treatment of a rail is to reveal either a minutely granular texture on the one hand, or a deeply pitted and furrowed structure on the other. Four such prepared sections are given in Plate 13. The extreme cases are represented by Fig. 53, which exhibits deep corrosion, and by Fig. 56, which is minutely granular and evenly attacked. Rails which are much corroded, as in Fig. 53, are often high in sulphur and phosphorus, low in manganese, but high in carbon. The corrosion indicates there has been much liquation or separation of the constituents of the ingot during solidification. This corroded structure is not inconsistent with durability in wear, nor with good results under the falling-weight test, even after prolonged wear. On the other hand, a finely granular rail, such as is shown in Fig. 56, usually indicates the presence of much manganese, that is, 0·9 per cent. or over. The tenacity of such a rail would be high, but its endurance under the falling-weight test would be low, and there is danger of a tendency to brittleness. Such a rail shows but little indication of the occurrence of liquation. From such etched sections it is easy to see which portion best deserves selection for the purpose of photo-micrography.

The photo-micrographs of each of the four transverse sections of rails shown in Plate 13 are given in Plates 14 and 15. They are arranged vertically, so that the photo-micrographs of rail 1 are Figs. 57, 59, and 61. The first photograph of each rail—Figs. 57, 58, 63, and 64—shows the structure of the exterior of the rail head, magnified 140 diameters. The second photograph in each set—Figs. 59, 60, 65, and 66—shows the interior of the head under the same magnification. The third—Figs. 61, 62, 67, and 68—shows the structure of a pearlite patch, magnified 850 diameters. Rail 1, which, as shown in Plate 13, was corroded unevenly in dilute sulphuric acid, revealed a structure that is generally characteristic of a good rail; the exterior is made up of small grains, Fig. 57, Plate 14, while the area of the ferrite is rather greater than that of the pearlite. In the interior, Fig. 59, the grains are larger, and the ratio of pearlite to ferrite is much greater than on the

exterior of the rail. Under the high power, Fig. 61, the pearlite shows well-defined laminæ, which differ greatly from those occurring in highly manganiferous rails. Rail 2 contains rather less carbon and phosphorus than rail 1. It gave good results in use. As seen in Figs. 58 and 60, the structure is more homogeneous than in rail 1, and the grains are somewhat smaller. Under the high power, Fig. 62, the carbide areas are found to be made up of good broad pearlite. Rails 1 and 2 both gave remarkably good results under the falling-weight test; with a tup weighing 2,240 lbs. and bearings placed three feet apart, they did not break until the height of fall was increased to 27 feet; the same result was obtained in each, whether the worn head was placed up or down. Rail 3 contains less carbon and more manganese than either rail 1 or rail 2. As seen from the similarity of Figs. 63 and 65, Plate 15, the structure is fairly homogeneous, the black pearlite area in the interior of the rail head, Fig. 65, being only slightly in excess of that on the exterior, Fig. 63. As shown in Fig. 67, the pearlite is somewhat granular, and the laminæ are not well defined. Under the falling-weight test this rail gave most variable results, fracture taking place with heights of fall varying from 2 to 10 feet. Rail 4 contains the most manganese of the series. Figs. 64 and 66 show that the ratio of the carbide to the ferrite areas is greater than in any of the other three rails. The grain itself is also much larger. Under the high magnification in Fig. 68, the pearlite is seen to be a minutely granular variety, and is highly characteristic of the larger percentage of manganese. The rail has high tensile strength, but is not one which would be capable of withstanding sudden shock; under the falling-weight test it broke with a height of fall varying from 6 to 10 feet.

In Fig. 69, Plate 16, is shown the general distribution of pearlite and ferrite areas in the entire transverse section of a rail. The extent to which the size and nature of the grain vary in different parts of the section is also well shown in the magnified Figs. 70 to 75 which surround the rail section. From the same rail are given in Plate 17 four photo-micrographs obtained from portions of metal cut from corresponding parts of transverse sections of the rail, but at points no less than ten feet apart. Thus Fig. 76 is cut from the

upper flange near the crop end of a rail; and its grain is slightly smaller than that shown in Fig. 77, which is from a corresponding point as regards the transverse section, but ten feet nearer the centre of the rail. Fig. 78 is from the interior of the lower flange of the crop end of the rail; and its grain is also smaller than that of a corresponding portion, Fig. 79, cut ten feet nearer the centre of the rail. It will be seen that, although in each case the grain nearer the centre of the rail is slightly larger than near the end, nevertheless the structures of the corresponding parts in the two transverse sections ten feet apart are closely similar. The smallness of the grain near the end of the rail in this example is undoubtedly due to the more rapid cooling of the end than of the centre. Even without making allowance for this fact, the difference in structure is not great: so that a transverse section cut from any part of the rail fairly represents the general structure of the rail throughout its length. The rail used in the preparation of Plates 16 and 17 is an exceptionally good one. The sections were given me by Mr. W. G. Kirkaldy; and the rail is one of six taken up near Misterton on the Great Northern and Great Eastern Joint Railway, between Doncaster and Gainsborough. It originally weighed 80 lbs. per yard, and after 17 years and 2 months wear weighed 77 lbs. Altogether about 50½ million tons of traffic had passed over it. The following are the results of the mechanical tests to which the rail was subjected:—tensile strength (bottom member) 45 tons per square inch; contraction of area at fracture 36 per cent.; extension in ten inches 18·8 per cent. The chemical analysis of the rail from metal cut near the head is as follows:—

	Per cent.
Iron (by difference)	98·389
Carbon	0·508
Silicon	0·091
Manganese	0·844
Sulphur	0·063
Arsenic	0·023
Copper	0·016
Phosphorus	0·066
	100·000

The question of rail steel has been considered merely in relation to the position it occupies in the freezing-point curve of carburized iron; and no attempt has been made to deal with the subject with any approximation to exhaustiveness. The foregoing remarks however will serve to indicate the direction in which work may be conducted, more particularly in relation to photo-micrography.

Mr. Thomas Andrews, as is well known, has dealt at great length with the structure of rails, and has illustrated his observations by drawings,* and has devoted special attention to the question of flaws. The nature of flaws has also been recently treated in an important paper by Mr. Stead,† whose great skill as a photo-micrographist lends special interest to the photo-micrographs by which his paper is illustrated. With regard to the size of grain: the relative dimensions of the areas of pearlite and of ferrite, as well as the size of the granules, afford valuable indications as to the qualities of the rail, and as to its probable durability. It has been shown by Martens ‡ that the size of the grain increases with the temperature at which the rail was rolled: whereas the strength and extensibility of the rail increase when the size of the grain diminishes. Rolling at too high a temperature seems to produce large meshes of ferrite enclosing pearlite; but within certain limits the higher the temperature of rolling, the greater are the strength and durability of the rail. It will be obvious that steel of the same composition must be considered in such a generalisation.

Mr. Sauveur found that the tenacity of rolled steel varies inversely as the size of the grain. M. Osmond § has recently shown that the results arrived at by Mr. Sauveur and M. Ljamin, as regards the relation between the size of grain and the physical properties of

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* *Engineering*, vols. lxiii and lxiv (1897), and lxv (1898). "Microscopic internal flaws inducing fracture in steel." Reprinted from *Engineering*, 10, 17, and 24 July, 1896.

† Proceedings Cleveland Institution of Engineers, 14 Nov. 1898, page 12.

‡ Mittheilungen aus den Königlichen technischen Versuchs-anstalt, vol. xiv, 1896, page 89.

§ Metallographist, vol. ii, 1899, page 78.

rolled steel, are not discordant. But it is necessary to compare steel of the same composition; for, speaking generally, the greater the amount of carbon and manganese in steel, the larger will be its grain and the greater its tenacity. For rails with transverse sleepers the falling-weight test appears to be more important than tensile tests. High tenacity is of course often accompanied by brittleness.

Effect of varying Thermal treatment on the structure of Steel.—Two varieties of steel were used to show the influence of thermal treatment. One was a low-carbon rail-steel, and the other a fairly pure die-steel higher in carbon. The metal cut from the low-carbon rail-steel shown in Plate 18 gave on analysis the following composition:—

	Per cent.
Iron (by difference)	98·828
Carbon	0·277
Silicon	0·006
Manganese	0·710
Sulphur	0·072
Arsenic	0·020
Phosphorus	0·087
	100·000

Fig. 80 is a photo-micrograph of a piece of this steel, magnified 850 diameters, which had been rolled at a bright red heat and allowed to cool slowly; here the pearlite has separated from the ferrite, while the laminæ of the pearlite are moderately well developed. Fig. 81 shows another sample of the same steel, which has been annealed for 18 hours at about 500° C. or 930° F.; here the carbide areas have contracted considerably, and mostly consist entirely of cementite. Fig. 82 shows the effect of heating this steel to 750° C. or 1,380° F., and quenching immediately in cold water; the carbide has partly separated out in the form of Troostite, which in this instance is of a ropey nature, and not much like that shown in Fig. 18, Plate 7; in Fig. 82 it is mostly embedded in a matrix of Martensite, as in Fig. 18. Fig. 83 is a photo-micrograph of a piece of the same steel, which has been quenched in water from a

temperature of over 1,000° C. or 1,830° F.; the result is the interlacing crystalline fibres which constitute Martensite.

The die steel used for the preparation of Plate 19 gave on analysis the following composition:—

	Per cent.
Iron (by difference)	98·93
Carbon	0·82
Silicon	0·05
Manganese	0·10
Sulphur	trace
Copper	——
Phosphorus	——
	99·90

All the photo-micrographs in Plate 19 are magnified 850 diameters. Fig. 84 shows the structure of a sample which has been forged and slowly cooled; here broad well-defined pearlite is visible. Fig. 85 shows the effect of annealing a specimen for about five hours at a temperature of about 600° C. or 1,110° F. In Fig. 86 are well shown the large crystallites of Martensite, produced by heating such a steel to about 1,000° C. or 1,830° F., and quenching in water. Fig. 87 indicates the tempered structure of the hard steel shown in Fig. 86; it was produced by reheating the quenched specimen, Fig. 86, to straw colour, about 243° C. or 470° F., and quenching in water. Fig. 88 shows the effect of quenching this steel at a temperature of about 750° C. or 1,380° F. When dies and other thick pieces of steel are quenched at too low a temperature, it often happens that a granular structure is produced, although often only in the interior of the mass. Should the article be a die, it will probably "sink" during use, owing to the softness of the centre; and the difference in tension between the centre and the outside will render it liable to crack. Fig. 89 is a photo-micrograph of burnt steel; a piece of the slowly cooled steel was heated in a porcelain tube to considerably over 1,100° C. or 2,000° F., and allowed to cool slowly. The microscope revealed that the structure consisted of ferrite, free graphite, and pearlite. The steel would not harden under repeated quenchings, and showed all the characteristics of

burnt steel. The cementite Fe_3C appears to become decomposed into ferrite and graphite.

Structure of Steel containing small percentages of Chromium.—Steel to which small quantities of ferro-chrome have been added has a much higher tensile strength, even after annealing, than ordinary steel of the same degree of carburization would have when similarly treated. When hardened in the usual way by quenching, the hardness penetrates more deeply in the chrome steel than in ordinary steel of the same carburization. These changes in mechanical properties it was thought would also be accompanied by a change of structure. Three kinds of excellent chrome steel were sent me by Mr. Webb from Crewe; and subsequent investigation proved that their structures, especially in the slowly cooled specimens, differed greatly from those of ordinary steel of the same carburization. Figs. 90 and 91, Plate 20, show respectively the structures, magnified 850 diameters, of a soft and a hard specimen of chrome steel, containing 0·32 per cent. of chromium and 0·44 per cent. of carbon; such a steel is well suited for tires and axles. In the soft specimen, Fig. 90, the carbide patches appear to be almost structureless, and the pearlite laminæ are very small. The crystallites constituting the Martensite in the hardened specimen, Fig. 91, are about normal for ordinary steel of the same carburization treated under similar conditions. In Figs. 92 and 93 are shown respectively the structures of soft and hard tool-steel, containing 0·46 per cent. of chromium and 0·85 per cent. of carbon. The soft structure, Fig. 92, greatly resembles the tempered structure of ordinary steel, and is composed of a minutely granular pearlite. The hard structure, Fig. 93, is that of Martensite; but the needle-like crystallites are smaller than those of a normal steel containing the same amount of carbon: compare Figs. 84 and 86, Plate 19. Soft and hard specimens of chrome spring-steel, containing 0·17 per cent. of chromium and 0·78 per cent. of carbon, were also prepared; and their appearance under the microscope is shown in Figs. 94 and 95, Plate 20. The soft specimen, Fig. 94, is mainly made up of extremely minute pearlite, with a few small patches of ferrite. The

hard specimen, Fig. 95, is composed of Martensite, the crystallites of which are smaller than those that would be produced in a normal steel of the same carburization if quenched under the same conditions.

Although these six specimens of steel contained such a small percentage of chromium, they were nevertheless found to be much harder in the slowly cooled state, Figs. 90–92–94, than ordinary steel similarly treated would have been. The quenched specimens, Figs. 91–93–95, were harder than quenched ordinary steel of the same carbon percentage; but this difference of hardness is not nearly so well marked in these three quenched varieties as it is in the three slowly cooled. From the above it is evident that the presence of chromium in small quantities tends to make the combined carbon more soluble, by replacing some of the iron in the iron carbide. This would support the view that in chrome steel the carbide is not entirely present as Fe_3C.

Discussion.

Sir WILLIAM C. ROBERTS-AUSTEN wished to express his deep sense of the loss that the Alloys Research Committee had sustained by the death of their chairman, Sir William Anderson. Adequate expressions of the truest sympathy had already, he knew, been communicated to Sir William Anderson's family; but on the part of those who were conducting the research he should like to say how deeply it was regretted that Sir William was no longer with them, because he had initiated this particular research into alloys, and had

taken the warmest interest in it as long as he lived. To the new President of the Institution he was most grateful for having accepted the chairmanship of the Committee. Had it not been for this fact, he feared he should himself have been discouraged from continuing the work any longer, because it made such severe demands upon his leisure. But with Sir William White as their chairman he hoped the Committee would be able to furnish at least one more Report. The present fifth Report he had been asked to prepare in readiness for this first meeting in the new building; and he felt it was a most flattering request, which however had resulted in the Report being somewhat hurriedly prepared. He wished also to say a word of grateful thanks to Dr. Alfred Stansfield, who had so long assisted him in conducting this research, but had now left him in the capacity of assistant for a post of greater activity as assistant professor to himself; and to Mr. Merrett, who had succeeded Dr. Stansfield; and to Mr. Brett, who had succeeded Mr. Merrett.

Mr. E. Windsor Richards, Past-President, desired to offer the congratulations of the Members present to Sir William Roberts-Austen upon the honour of knighthood, which had at the beginning of this year been conferred on him by Her Majesty; and to express their hope that he and Lady Roberts-Austen would live long to enjoy this distinction. These researches into the structure and constituents of steel had been undertaken, he had no doubt, with a view to throw more light on a most difficult subject, and at the same time to enable manufacturers to improve the quality of their productions. Considering himself to be what was termed a practical man, he was trying in his own mind to put the substance of the present Report into a form which should be of some use in steel works; but he was greatly troubled with so many "ites." Ferrite he could understand, and cementite also he could grasp. Then there was pearlite, which was said to resemble mother of pearl; and this he could picture fairly well in his mind. But what was meant by Martensite, and by Sorbite? by Troostite? and lastly by Austenite? It seemed to him that the magnified sections of steel illustrating the Report represented only a tiny spot of the steel. Interesting and beautiful as the

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sections were, yet looking at that of Austenite and Martensite, shown in Fig. 22, Plate 7, it was rather difficult he thought to distinguish one substance from the other with the naked eye; and when it was considered that it was here magnified 850 times, it seemed to him it was such a small speck of the whole piece of steel that he was not able to believe it was a fair representation of the quality of the steel. Even if the piece of steel operated upon were only about half an inch square, Fig. 22 ought to be about 35 feet square in order that it might represent the whole of so small an area. Then an opinion could be formed as to what quantity of Austenite and Martensite there was in the area of half an inch square. It surely could not be that the piece of steel was all Austenite and Martensite: there must be other constituents in it. Again, supposing a succession of thin slices, say only 1–100th of an inch thick, were taken off the section, would there still be the same arrangement and proportion of Austenite and Martensite in each slice? and so on throughout the whole length of the bar?* Steel bars were now rolled in England as much as 300 feet long. Looking at Figs. 21 and 22, was it to be understood that the whole length of a bar, weighing something like a ton and a half, rolled from an ingot containing 1·8 per cent. of carbon, would be all Austenite and Martensite?

Sir William Roberts-Austen said yes, if it had received the same thermal treatment throughout its entire length.

Mr. Windsor Richards asked at what period of its manufacture? when it first came out of the heating furnace? or when it was finished?

Sir William Roberts-Austen said Martensite and Austenite were both constituents of hardened steel. The metal would have to be quenched in order to produce them.

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* At the time this question was asked, the information contained in page 63 had not been supplied.

Mr. Windsor Richards was much puzzled to know whether all these ingredients of steel were metalloids, or earthy matters, or occluded gases seeking liberation, or cleavages of crystals. The late Mr. Daniel Adamson he remembered a good many years ago speaking highly of steel as a homogeneous soft metal, and comparing it with that "dirty nasty stuff" iron, which he called "concrete." Some of the sections shown in Plates 6 to 15 certainly bore a striking resemblance to concrete. For many years past the belief had been entertained that the steel now made was a remarkably homogeneous metal; and now it seemed as though an attempt were being made to undermine this belief, and to make out that the whole of such a bar of steel as he had described was of the nature of concrete. Before many more of these "ites" were discovered, would it be possible to arrange a nomenclature which would be more easily comprehended by ordinary minds? The present names appeared to him to be given empirically by godfathers self-ordained. The photographs shown by Sir William Roberts-Austen were most interesting; the amount of time and labour that he had given to this study must have been prodigious; and he deserved the warmest thanks of the Institution for all that he had done.

The President thought the illustrations exhibited by Sir William Roberts-Austen had been considered by the members present to be the most attractive part of the proceedings. Whatever might be said about the "ites," it appeared to him that the great varieties of structure shown by the illustrations must mean something, even though it was not yet known fully what they did mean.

Mr. Windsor Richards said he was asking only for a better definition of the several new ingredients.

Mr. J. E. Stead considered the beautiful pyrometrical improvement which Sir William Roberts-Austen had made since his last Report was likely to be of great service in studying the thermal changes taking place in alloys. Also he must congratulate him upon having discovered some new halting points in the cooling curve

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of electro-iron. Although it could not be seen at present that these new halting points were of any practical value, still it was quite possible that they would be found to have some important bearing upon the metallurgy of steel. One question which arose was, whether it might not be really the fact that the hydrogen blown through the Bessemer converter in the moisture contained in the blast was in some way responsible for the somewhat variable results obtained by the Bessemer process, in comparison with those from the open-hearth process. He was glad that this matter was being studied by Sir William, and hoped that in his next report, or on some other future occasion, he would give the Institution the benefit of his further researches. A point of great interest in Plate 2 was that the remarkable halt Ar 3 was coincident with the breaking up of the structure of coarse-grained steels when they were heated up to this temperature: that is, if soft iron—not steel, but practically a carbonless iron, highly brittle owing to its large crystalline structure—was heated steadily up through the successive halting points Ar 1, Ar 2, and Ar 3, the change or breaking up of the coarse structure took place instantly on reaching the point Ar 3, where the great evolution of heat was noticed in cooling down. This coincidence was most interesting indeed, and showed that there was some wonderful internal change taking place in the heated metal. It was indicated not only by a thermal change, but also by a structural change; and it seemed to him that here was pretty strong evidence, or corroborative evidence, of the existence of allotropic change at the point Ar 3. The thirteen illustrations shown in Plates 21 to 23 bore more directly upon the practical side of this subject.

The statement of the late Mr. Daniel Adamson that iron was a "concrete" mass had been quoted by Mr. Richards; and the diagram, Fig. 109, Plate 23, showed pretty clearly what steel containing various percentages of carbon was really composed of when cooled rapidly. The diagram was divided into squares, representing the percentage of carbon along the horizontal lines, and on the vertical lines the percentage of the constituent compounds it formed with the iron. When there was no carbon at all, the whole height of the diagram up to 100 represented the iron: that is, there was 100 per cent. of

ferrite, or iron free from carbon. But when there was 0·9 per cent. of carbon, there was no free iron as massive ferrite, but there was 100 per cent. of pearlite. The pearlite structure was shown by the shaded area. The composition of the pearlite or eutectic of iron was 86·65 per cent. of pure iron or ferrite Fe, and 13·35 per cent. of carbide of iron or cementite Fe_3C. Immediately that the carbon was increased above 0·9 per cent., free massive cementite or carbide of iron Fe_3C began to appear, containing 93·33 per cent. of pure iron and 6·67 per cent. of carbon. For any percentage of carbon it could be seen from the diagram what proportion of ferrite, pearlite, and cementite was present in the mass. Taking, for instance, about 0·5 per cent. of carbon, and running vertically up the corresponding ordinate, a steel would be found containing about 45 per cent. of ferrite and about 55 per cent. of pearlite. The pearlite structure, or the eutectic of iron, he believed had been called by Professor Arnold true steel; it was the most homogeneous of all the steels. If there was less than 0·9 per cent. of carbon, free iron or ferrite existed; if there was more than this percentage of carbon, free cementite, a hard substance, existed from the point P. Iron might be made to combine with as much as 4·8 per cent. of carbon; but even with this maximum amount of combined carbon there was still a certain proportion of the pearlite structure accompanying the mass of cementite, as seen in the diagram, Fig. 109, Plate 23.

In page 54 Sir William Roberts-Austen had referred to certain results which he had himself communicated to him, as to the small amount of carbon that would separate in the free state from iron containing 0·04 per cent. of carbon. Fig. 96, Plate 21, was a section, magnified 50 diameters, of a highly brittle annealed piece of soft Swedish steel containing 0·04 per cent. of carbon, showing the free cementite in small white patches. It was not pearlite in this instance, and that was the peculiarity. The ground mass of the section was ferrite. On breaking this steel, fractures passed through the ferrite, and not through the brittle cementite. It had been said by Sir William Roberts-Austen (page 54) that it was a rare occurrence to have a mass of cementite in soft steel; but

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he thought exception must be taken to that statement, because, although it was a rare occurrence to have it in massive pieces of soft iron, yet thousands of tons of the thin soft-iron sheets which were annually made into plates and galvanized, and sent out of this country to all parts of the world, had practically all got carbon massed together in them in the state of cementite. The peculiarity about the massive pieces of soft steel was that, although they were annealed in the same way as the thinner sheets, yet as a rule the annealing did not cause the segregation of cementite.

In Fig. 97, Plate 21, was shown a structure of a piece of soft steel containing 0·15 per cent. of carbon, magnified 50 diameters, which was developed by heating to whiteness, about 1,300° C. or 2,370° F., and then quenching it in water. This showed the Martensite structure in soft steel. The carbide appeared to diffuse itself throughout the whole area of the section; and when etched with nitric acid diluted with five times its weight of water, the structure looked as if it had been brushed over right and left with dark coloured paint, but always in straight lines, never in curves. This was the peculiarity of Martensite structure. There was a marvellous difference between this and the same steel unquenched.

In Fig. 98, Plate 21, was represented a polished and etched section of steel containing about 0·27 per cent. of carbon, magnified 200 diameters. It had been slowly cooled by placing it in the centre of a large mass of molten blast-furnace slag and allowing it to cool down with this; the time taken to cool from about 1,300° C. or 2,370° F. down to 15° C. or 60° F. was more than 48 hours. The structure of this steel differed from that of any of those shown by Sir William Roberts-Austen, inasmuch as the pearlite areas were here surrounded with massive envelopes of cementite. This was evidence that, on very slowly cooling steels containing little carbon, say from 0·1 to 0·4 per cent., the fine laminæ of the cementite in the pearlite tended to fall together or coalesce, and form massive cementite bands; and that probably, if the cooling was sufficiently slow, the pearlite would be entirely replaced by an equivalent quantity of massive cementite. On heating this sample to just above 700° C. or 1,300° F., and then quenching it in water, the

pearlite areas were converted into Martensite areas of hard steel, and on polishing stood out in bold relief above the surface of the polished section.

Fig. 99, Plate 21, exhibited the structure of tool steel containing 1·38 per cent. of carbon, magnified 30 diameters, which had been heated up to about 1,300° C. or 2,370° F. inside a molten slag ball, and annealed by being left to cool down inside the ball.

The microscope revealed certain structures, and what mechanical engineers required to know was what was the weakest part. It would naturally be expected that the hard brittle carbide or cementite would be the part most fragile and easily broken; and on placing the specimen upon a little hollow dished-out block of metal, and applying a blow on the back of it with a hammer, it was found that a fracture occurred along the weakest lines. If the blow was not too violent, so as not to fracture it completely, the specimen could be removed back to the microscope, and it could be ascertained exactly where the fracture had traversed it. In this way it was possible to determine precisely what part of the structure was the weakest. In the specimen of soft annealed steel shown in Fig. 96, which contained very little carbide, the fracture passed right through the middle of the grains, following the cleavage planes of the crystalline grains. In the specimen shown in Fig. 99 the fracture, instead of passing through the grains, passed along the lines of the white cementite meshes surrounding the dark pearlite grains.

The scoriaceous areas in steel were a most important subject. It was Professor Arnold of Sheffield who first discovered some time ago that, in small castings of steel containing sulphur, the sulphur or sulphides were thrown to the sides of the crystalline grains, and formed envelopes of a highly brittle character. Such a casting, built up of crystalline grains so enveloped, was exceedingly brittle. A specimen of this kind was shown in Fig. 100, Plate 21; the grains of steel were here meshed round with sulphide of manganese. In this particular character of brittle steel Professor Arnold had found that, after it had been heated up to a certain temperature, the scoriaceous sulphide areas segregated into globules, and the steel lost all of its brittle character. If the casting was large

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enough, he had himself found that the heat in the mass was sufficiently great to cause this segregation or balling up of the sulphide. The weakness caused by the meshing of sulphides was not likely therefore to occur in a large casting when sulphur was present, but in small castings only.

In Fig. 101, Plate 21, magnified 130 times, was shown a structure of a steel rail head, such as had not been shown by Sir William Roberts-Austen. Here the peculiarity was that the rail head had broken away or laminated badly on one side: a peculiarity which was coincident with the dark pearlite and light ferrite areas being here arranged in parallel seams. Had the two, as was usual, been intimately mixed up together, he anticipated that the lamination would not have occurred. The lenticular slag-areas of intermediate tint in Figs. 101 and 102, were sulphide areas, and consisted in these instances of sulphide of manganese. They originally existed in the ingot as microscopic globules; but on rolling the ingots they became elongated, and assumed a more or less cigar-shaped form. In Fig. 103, Plate 22, was shown a section of the same steel after crushing; the scoriaceous areas had here been narrowed and lengthened, like the ferrite and pearlite in which they were interspersed. To these sulphide or scoriaceous areas in steel rails attention had been directed by certain investigators, who had assumed, perhaps prematurely, that the scoria was responsible in a great measure for the deterioration of the steel rails, axles, shafts, &c. If scoria had such an evil effect in steel, how much greater effect should be produced by the larger quantity of it in wrought-iron; for as a rule ten times as much scoria would be found in the piled wrought-iron as in the steel.

In Fig. 104, Plate 22, was shown a longitudinal section of good wrought-iron, magnified 50 diameters; the iron was represented by the light part, and the dark part represented the cinder or scoriaceous matter. The bar of iron, from which this section was obtained, was about $\frac{3}{4}$ inch diameter, and was actually tied when cold into a knot, and bore almost any amount of severe treatment without breaking. In spite therefore of all these large masses of scoriaceous matter in the iron, it was of excellent quality; and as this much larger quantity of

scoria, always present in good iron, did not of itself cause it to be easily fractured, it appeared to be premature to assume that a fraction of this amount would be dangerous in steel. In studying micro-structures the greatest care he thought was needed before drawing practical conclusions. The sulphide areas or masses, in the most sulphurous steel that he had ever examined, he estimated at not more than a half of one per cent. The best iron shafts of steamers and axles of wagons, etc., contained from 1 to 2 per cent. of scoriaceous matter.

As supplementing Sir William Roberts-Austen's sections illustrating the structure of the heads of rails, Fig. 105, Plate 22, showed a portion of the surface, natural size, of the head of the steel rail which had caused the accident at St. Neot's on the Great Northern Railway (10 November 1895). The trains travelled from left to right, and the steel flowed in the same direction. With regard to the transverse curved cracks in this rail, and in some of thirty or forty other rails which he had examined, his experience had shown clearly that they did not develop, unless the rail head became greatly worn down and flat at the crown. When the rail head had become so much worn, there were two reasons why the cracks should then develop. The first was that, when the rail became so flat, there was little side flow of the material; the flow was mainly in the longitudinal direction, and the steel could not travel along the whole length of the rail and go off at the far end. Instead of doing so, the particles behind were forced or crushed forward over the particles in front. The longitudinal vertical section of the St. Neot's rail head in Fig. 106, magnified 10 diameters, which had been polished and etched with nitric acid and then re-polished, showed that the top part had been travelling in the direction in which the trains passed over it. It also showed the hammer-hardened skin of the upper surface, with the curved transverse cracks through it, and the porosities or minute cavities that had originally contained sulphide of manganese, which however had been removed by the etching liquid. These latter illustrated Sir William Roberts-Austen's remarks on molecular porosity in a former Report (Proceedings 1893, pages 106–7).

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In Fig. 107, Plate 22, was shown, not a rail head, but the surface of a worn locomotive tire, magnified 50 diameters, showing how the steel was crushed and tended to flow round the circumference. Fracture was easily effected along the lines from left to right. The same cracks were liable to occur in a locomotive steel tire as in a steel rail. Although they were scarcely visible, yet on taking a thin transverse section from the surface, and testing it by bending it in the way he had already described, with the worn surface downwards, the bending invariably formed the same kind of curved cracks that were seen in Fig. 106 in the surface of the St. Neot's rail head. He had been informed by a competent authority that cracks apparently did not grow in locomotive steel tires as they did in steel rails. So far as his own experience went, the cracks never penetrated to any great depth in a tire, but were only superficial. This pointed to the conclusion that, as there was no possibility of flexure in the tire, because it was perfectly rigid on the wheel, the cracks were developed first of all by the flowing of the steel over itself, and did not gradually increase in depth, as they did in steel rails, which were not supported so rigidly.

The second cause for the development of cracks was apparently to his mind the comparatively coarse crystalline structure of the interior part of the rail head. It had been shown clearly by Mr. A. Sauveur,* whose work had been fully confirmed by himself, that in the exterior portion of a rail and in the upper surface of a new rail head, the structure was of a much finer grain than in the interior. It was well known that a coarse grained steel was much more liable to fracture than one of fine grain. It appeared to him probable therefore that a second cause for the development of cracks in the rail head and in the tire might be the large size of the crystalline grains. In all the steel rails that he had examined which showed a development of cracks, the cracks had been found in those portions of the rail heads which were the most coarsely granular. Even if this was regarded as only

* American Institute of Mining Engineers, Chicago Meeting, 1893; and Cleveland Institution of Engineers, 14 November 1898, pages 26–8.

a coincidence, still it pointed in the direction of having for rails and tires steel of fine grain throughout the whole mass. How was this to be obtained? In his present Report (page 64) Sir William Roberts-Austen had referred to the fact that, if steel was rolled at a comparatively low temperature, finer grain was obtained; and had said that, the higher the temperature at which it was rolled, the coarser was the grain. It was hardly possible he feared that steel manufacturers could be expected to work with any more scientific accuracy than they did at the present time in making steel rails; they were doing their best, and it seemed hardly likely they could be induced to employ the highly sensitive pyrometer described in these Reports, and by means of its records to obtain the exact temperature which would give the best structure to the steel. Therefore he was inclined to believe that the best practical way to treat the steel, after it had partially cooled down, was by simply heating it up to a temperature at which the carbon diffused out of the pearlite into the ferrite: a condition of things that was invariably accompanied by a breaking up of the structure. According to the researches of Brinell,* steel after it had cooled down to a certain critical point, no matter how coarse might be its grain, was invariably broken up into a fine structure on reheating to a certain critical point between 700° and 850° C. or 1,300° and 1,550° F. This he had himself confirmed as an undoubted fact; in experimenting upon pieces of rails he had found it was quite easy to obtain throughout the whole section a beautifully fine structure; and it seemed to him that this was what really should be aimed at. Whether the manufacturers and the users of steel rails would feel inclined to pay the extra 1*s*. or 1*s*. 6*d*. a ton, which would be necessary in order to get this finer structure for their rails, he could not say; but he thought the trial was well worth making.

As already mentioned in page 76, it had been stated by certain investigators that the sulphur flaws which were represented in Figs. 101 and 102, Plates 21 and 22, had a tendency in steel rails to cause the material to develop fractures under fatigue or work. But in Figs. 102

* "Metallurgy of Steel"; by Professor Henry M. Howe. New York, 1890.

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and 103, Plate 22, were shown specimens of really excellent steel, having a large elongation and a high tenacity ; it was from a tail shaft of a screw propeller. On micro-mechanically testing it in the manner already described, he had found after crushing it that the fracture did not traverse through the scoriaceous areas, one of which was shown at S, Fig. 103, but along the borders of the pearlite areas, missing the scoriaceous areas altogether. It appeared to him therefore that the weakness was here due to the laminæ of the pearlite being pressed together into horizontal layers, and that fracture passed between these flattened plates, and that the scoria was not responsible for the weakness.

In Fig. 108, Plate 23, was shown a section of annealed soft steel containing 0·12 per cent. of carbon, which illustrated the wonderful effect of treatment by heat. By annealing at a low temperature it had been crystallized in coarse grains, as seen in the left-hand half of Fig. 108. On heating it up to just above the critical point Ar 3, about 900° C. or 1,650° F., and then quenching it in water, it was found that the whole of the coarse structure had disappeared, and the beautiful fine-grained structure seen in the right-hand half of Fig. 108 had been developed. This specimen therefore afforded another illustration of the fact that the abrupt and enormous absorption of heat at Ar 3, in heating up steel with little carbon in it, was exactly coincident with the breaking up of the crystalline structure.

Professor J. O. Arnold had read the present Report with much interest and gratification. In connection with the first and second Reports (Proceedings 1891, page 587, and 1893, page 154–5) he had strongly suggested the necessity of correlating the results obtained by the Alloys Research Committee with those arrived at by the microscopic examination of the structures ; and also that hydrogen might possibly be the cause of the point of recalescence Ar 3 in the cooling curve (1893, page 158). At that time it had seemed to him that Sir William Roberts-Austen was not inclined to attach much value to those suggestions ; and therefore he was greatly pleased to find that the present Report was largely taken up with micro-sections

and with a description of the newly discovered recalescent point of hydrogen. He joined with Mr. Stead sincerely in congratulating Sir William on the really beautiful arrangement of the pyrometer for registering small evolutions of heat; it must indeed, as Mr. Stead had remarked (page 71), be of great value. With reference to the evolution of heat at 487° C. or 908° F., Mr. Stead had observed (page 72) that it was not quite evident at present what the practical interpretation of this point should be. He should therefore like to suggest for consideration that, in boiler-plate steel and ship-plate steel, there was often found a critical mechanical point at what was called a black heat. If the boiler plates or the ship plates were worked at that heat, as in bending operations, they assumed an extraordinary brittleness. The point at which their brittleness came on seemed to him to be just about the temperature of the hydrogen evolution; and it would be a good thing if the two occurrences could be associated with each other, and if it could be definitely shown that the brittleness encountered in working steel at a black heat was due in some degree to hydrogen between the crystals.

As an analogue for steel, frozen brine had been selected by Sir William Roberts-Austen; and while some might naturally be inclined to take such an analogue a little coldly and with a grain of salt, it appeared to himself that the comparison was broadly a good one, and would apply well to illustrate the points which Sir William desired to bring out. One question which he should like to ask was, whether the two terms eutectic and cryo-hydrate were meant to be synonymous. If the term eutectic referred to the solid whilst still in solution, which in the frozen brine was the cryo-hydrate, and which in the steel would correspond with what might be called the cryo-carbide at 0·9 per cent. of carbon, then they seemed to be synonymous. But was it admitted that the cryo-hydrate in the liquid brine was certainly a eutectic mixture without any combination? If, as the use of the name cryo-hydrate might seem to imply, it was understood to be a genuine chemical combination in solution, but a decomposed mixture when solid, then he accepted the analogue altogether.

With reference to the carbon-solution curves in the diagram, Plate 5, direct measurements of the diffusion of carbon and of twelve other

(Professor J. O. Arnold.)

elements through hot iron had been made during the past two years at University College, Sheffield; and the data there obtained did not exactly agree with some of those contained in this Report. It seemed to be thought that carbon—or, as he should himself prefer to call it, carbide—was insoluble in what was called β iron. Referring to Plate 5, the range of β iron lay between the two points of recalescence Ar 2 and Ar 3; and if he rightly understood the Report, it was considered that carbon would not diffuse within that range of temperature, and that the iron must pass above the higher point Ar 3 before diffusion could begin to take place. The results however of the direct measurements made at Sheffield were that the diffusion did really commence just above Ar 2, at which temperature the carbon began to diffuse into the iron, and a diffusion diagram was obtained something like that shown in Fig. 110, Plate 23, in which the temperature was measured vertically and the percentage of carbon horizontally. It was found that the carbon, in the form of carbide of iron, was insoluble in the iron up the line AB until the point Ar 2 was touched at about 760° C. or 1,400° F. At about this temperature, given a sufficient time and an excess of carbide, the iron could be saturated along the horizontal line BD up to 0·9 per cent. of carbon, or the cryo-carbide point of carbon. After this, on further raising the temperature with an excess of carbide still present, there was a gap DE of at least 150° C. or 270° F., possibly of 200° C. or 360° F., where the percentage of carbon remained stationary, so that the line DE was vertical; and it was only when the temperature reached from 900° to 950° C., or 1,650° to 1,740° F., that the diffusion went on again along the horizontal line EG, and the steel could be fed up to 2 per cent. of carbon.

The true meaning involved in the terms used in the Report—α iron, β iron, and γ iron—resolved itself largely he thought into a question of definition. The definition of allotropy employed originally and up till ten years ago had clearly implied a chemical allotropy. The latest definition given by Sir William Roberts-Austen of the phenomenon of allotropy, and now confirmed by him, was that it was a change in the internal energy of a mass at a critical temperature,

unaccompanied by any change of state. If this was accepted as a definition of allotropy, then undoubtedly the diagram Fig. 110 pointed to allotropic iron; and he was himself fully prepared to accept the definition, provided it was fully applied, because then it would mean, he thought, that water between 4° and 0° C., or 39° and 32° F., during the time it was expanding and before it formed ice, was an allotropic modification of water. This however would be a new definition, he thought, so far as standard works on chemistry were concerned; but if it were accepted, he was fully prepared to admit that the changes in iron were allotropic, though on the original chemical definition he could not admit it.

There was one analogy in the Report (page 50) which he could not quite follow: namely the separation of carbon from iron as a carbide or well marked binary compound Fe_3C, and the separation of copper sulphate $Cu\ SO_4$ from its solution as $Cu\ SO_4 + 5H_2O$. Here the copper sulphate represented the carbide, and the water represented the iron. Now the solution of sulphate of copper, which was blue vitriol, would be somewhat difficult to assimilate physically; and he found the same difficulty metaphorically with the analogy.

The series of steels which he had himself studied at Sheffield had been referred to in page 52 as being in their normal state, when in the condition in which they came from the rolls. This however was a misapprehension; for the steel as it came from the rolls might be in an abnormal state, owing to the difficulties in the finishing temperature; and therefore to make the bars normal they were all carefully heated up to 1,000° C. or 1,850° F., and allowed to cool in air, so as to set them all through in the same thermal state.

The results given by Professor Howe, referred to in page 52, he thought might now be regarded as obsolete. The mechanical influence of carbon on steel was known, or at least the hallucination prevailed in Sheffield that it was now understood; and Professor Howe's results did not agree with many which he had himself obtained. The maximum stress recorded in Professor Howe's figures was about 48 tons per square inch, and the greatest elongation recorded was 38 per cent.; whereas in Sheffield 62 tons and 50 per cent. had

(Professor J. O. Arnold.)

been obtained. Moreover the Sheffield tests had been made over and over again; and the results which he had published in a paper read before the Institution of Civil Engineers on the influence of carbon upon iron (Proceedings vol. cxxiii, 1895, page 127) represented so large a number of tests that he thought they might be considered to represent fairly the mechanical influence of carbon upon the purest commercial iron known. For this reason it seemed to him that Professor Howe's results had now become obsolete. The tensile strength of 62 tons per square inch in steel containing 1·2 per cent. of carbon was the maximum stress he had himself obtained with the purest crucible cast steel, after either annealing or forging.

Some such protest as that made by Mr. Windsor Richards (page 69) was what he had been expecting from practical men for some time; and although he could not himself go so far in depreciating the value of micro-graphic analysis, he nevertheless thought there was some solid ground for complaint. The needless multiplication of allotropic modifications and constituents he thought was becoming too much altogether. It was true that steel was generally admitted to resemble closely a crystallized igneous rock, such as granite, and that therefore, as in mineralogy, its constituents might appropriately have names given to them ending in "ite." Professor Howe he thought had been the first of the self-ordained sponsors contemplated by Mr. Richards; and he had named ferrite, pearlite, and cementite, three well-known constituents discovered by Dr. Sorby; these names he thought were excellent, and they had been generally accepted, and appeared to be approved by Mr. Richards himself. But with regard to Martensite, Troostite, Sorbite, and Austenite, he feared a good deal of confusion already in these early days was creeping into the science of metallurgy through synonyms, which must be a great trouble to students, and upon which the chief authorities were by no means agreed. For instance, that which in page 56 and Fig. 18, Plate 7, was called Troostite, he called Martensite; and what was called Martensite in page 56 and Fig. 6 (page 55) and in Fig. 19, he was unable to understand at all by this designation, and it seemed to him to illustrate a great fault in the

nomenclature adopted. Martensite had been defined as steel containing from 0·1 to 0·9 per cent. of carbon quenched out; in the cross section therefore of such a bar so treated the whole structure consisted of Martensite throughout. Now the first characteristic property of a mineral constituent was that it should have a fairly definite composition and a fairly definite hardness: in fact the scale of hardness generally employed was based upon certain minerals whose hardness was constant. But if a structure of hardened steel, containing from 0·1 to 0·9 per cent. of carbon, was to be called Martensite, it presented an extraordinary paradox as a mineral constituent. For if a crushing piece of steel, containing 0·1 per cent. of carbon, 0·564 inch diameter and 1 inch high, was hardened and tested by compression, it would crush down into an ordinary cheese-shaped piece, which had undergone perhaps 55 per cent. of compression. But if a steel containing 0·9 per cent. of carbon was treated in the same way, there was absolutely no compression obtained. Again a bar of the steel containing 0·1 per cent. of carbon quenched out could be bent double, twisted, rolled up, and tortured in any other way; it was perfectly tough. But the steel containing 0·9 per cent. of carbon was as brittle as glass. Therefore it seemed to him that, if Martensite and the other terms were to be of any practical use to engineers, they should convey to the mind some idea of the property of the material. The properties of ferrite, of pearlite, and of cementite were known; but Martensite, as defined by M. Osmond, Sir William Roberts-Austen, and Mr. A. Sauveur, seemed to him to cover an indefinite range of properties, and he therefore considered the name altogether inappropriate: in fact, except under certain conditions, he could not recognise it as indicating a distinct constituent. Austenite was obtained by quenching suddenly from a high temperature a steel containing say 1·6 per cent. of carbon. If a razor steel was treated in that way, he was afraid the effect would be disastrous: the property of such a razor would be, in the vernacular of the Sheffield grinders, "it'll oupen an' shoot, but it waint coot."

From a scientific point of view, the question of the properties of iron and steel seemed to him to have been argued in a circle for ten

(Professor J. O. Arnold.)

years past, and to have come back again almost to the same point. But this having been done, both sides he thought were now practically agreed that their views had been brought to coincide by the evidence adduced on either side. The crucial question was, whether the carbon in hardened steel was in solution as carbon in the free state, or whether it was diffused as a carbide of iron. If it might be present as a carbide—as he thought Sir William Roberts-Austen was willing to admit, and as had already been admitted by M. Osmond and by a long line of metallurgists in England and other countries—then he thought the fifth Report of the Alloys Research Committee might be considered to be particularly valuable as ending a controversy which had been carried on so long.

Mr. Thomas Wrightson joined in the congratulations to Sir William Roberts-Austen upon the great improvement he had made in the recording pyrometer, by duplicating the thermo-junction and also the galvanometer. By these means he was enabled to get on a larger scale the curve representing the thermal changes which he was now investigating. These changes were highly interesting; and engineers might now look forward to the day when a defect produced by such natural change in the material might be neutralised by applying processes during the time it was passing through the change. In Plate 2 were shown three or four remarkable changes. Not being a chemist, he could not discuss the question of allotropy from the chemical point of view; but he thought that Sir William Roberts-Austen was quite right in regarding these changes as a physical allotropy. The changes might indeed be of great importance in future experiments in the process of iron and steel manufacture. It was quite conceivable that iron or steel, before it arrived at one of these critical periods, could be affected by any particular process in quite a different way from that in which it would be affected while passing through that critical period. Sir William he thought had done great service to science in investigating what these changes were, and had dealt with three or four of the most important changes. He should himself like to draw attention to another change at a higher temperature than had been reached in Plate 2. Some years ago he

had made many experiments upon the remarkable change which occurred in iron at the much higher temperature of from 1,300° to 1,400° C. or 2,370° to 2,550° F.; and between these limits he had found that iron had the remarkable property of reversing the ordinary law of contraction by cooling, and it expanded in cooling during this period. As he had described on a former occasion (Proceedings 1895, pages 283–9), this had been determined with regard to cast-iron by experiments on the flotation of balls of solidified iron in liquid iron. At the time of making those experiments he thought it was likely that this expansion in cooling was connected in some way with the curious property of the regelation of ice. The fact had been mentioned by Professor Arnold (page 83) that between 0° and 4° C. or 32° and 39° F. there was a similar change in water, which in cooling expanded instead of contracting, and thereby caused the remarkable phenomenon of regelation in ice: that is, when two wet surfaces of ice were pressed together, freezing took place. These phenomena were analogous to the welding of iron, and he thought might be intimately connected therewith. The difficulty he had met with in experimenting with wrought-iron by the flotation process was that wrought-iron became so viscous in melting that it was impossible to float solid wrought-iron in liquid wrought-iron, because immediately the ball of solidified wrought-iron was put into the liquid wrought-iron, the liquid wrought-iron became so viscous that the buoyancy of the solidified wrought-iron could not be observed. Sir William Roberts-Austen, with whom he had talked the matter over, had kindly undertaken to join him in investigating it at the Mint. They had abandoned the idea of attempting to float the solidified wrought-iron in the liquid wrought-iron, and had approached the matter from quite a different direction. About fifty years ago Lord Kelvin and his brother, the late Professor James Thomson, had proved, not only mathematically but experimentally, that any substance which reversed the ordinary law, and expanded in cooling, would also cool by pressure; and a series of experiments had been arranged at the Mint by Sir William Roberts-Austen and himself, whereby they could examine the cooling which was produced by compressing

(Mr. Thomas Wrightson.)

wrought-iron at high temperatures. Rods of wrought-iron were placed in an apparatus somewhat similar to that shown in Fig. 2 (page 38), and were pressed endwise by a hydraulic press, while heated at the same time by a Thomson-Houston electric welding machine (see Proceedings 1895, Plate 44, Fig. 14). As soon as the iron came to the welding temperature, it was shown by a similar apparatus to that sketched in Figs. 1 and 2 (page 38); the thermo-electric junction was passed into the centre of the rod and connected with the galvanometer, and a ray of light from the mirror of the galvanometer was received upon a travelling photographic slide moved by clockwork. A curve was thereby obtained, which showed whether the temperature was rising or falling; and it was found that, when the iron reached a temperature anywhere between 1,300° and 1,420° C. or 2,370° and 2,590° F., any pressure to which it was subjected caused a fall in temperature (Proceedings 1895, Plate 45). This was an important verification, because it also implied, according to the law discovered by Professor James Thomson and elaborated by Lord Kelvin, that within these limits of temperature the iron would also expand in cooling; and therefore this method had enabled that critical period to be examined in a highly satisfactory way.

With regard to the other periods of change in the property of iron as it passed through the different ranges of temperature, he thought it was quite reasonable to suppose that, as in the case of hammering or pressing in welding, processes chemical or physical applied to the iron during these other critical periods might most probably have a permanent influence upon the qualities of the material, which it would be of extreme interest to mechanical engineers to understand. He trusted therefore that Sir William Roberts-Austen would continue these investigations, because he believed investigations of this kind were the foundation of knowledge in this particular branch of science; and he had no doubt that he would thereby succeed in making a much more exact science of a subject which up to the present time had been mainly a matter of rule of thumb.

Dr. Alfred Stansfield drew attention in the diagram, Plate 5, to the part of the curve SE, beyond the point E, which was shown dotted in the diagram. In the fourth Report (1897, Plate 11) the line SE was left off at about the point E; and the reason of its not being continued further was that the amount of heat given out by the separation of cementite, which produced the points on the curve between S and E, was so small that it was difficult to determine their exact position, especially at the higher temperatures. There were other considerations however which enabled a prolongation of the curve SE to be attempted in a general way. The vertical ordinates of the curve SE, measured from the horizontal line SP, indicated the amount of free cementite in the steel; and therefore, even when the positions of points on the curve could not be proved by the ordinary cooling-curve method, the approximate height at which the curve should be drawn might be found, for high-carbon iron containing more than 1½ per cent. of carbon, by simply estimating under a microscope, or ascertaining by chemical analysis, the amount of free cementite that was present. The curves in Plate 5 represented samples of fairly pure carbon pig-iron—not white or manganese pig-iron—which had been cooled slowly from temperatures above their melting point. Under these conditions it was known that the amount of cementite decreased with the increase of total carbon in the iron beyond a certain amount of carbon; and consequently somewhere beyond the point E the curve should turn down. It might even be possible to reach a percentage of carbon K, say perhaps about 4·2 per cent., at which the cementite ceased to be present at all, and free ferrite came in, as indicated by the ascending dotted curve KL.

The interesting example of diffusion, given by Professor Arnold in Fig. 110, Plate 23, was in no way at variance with the views put forward in the present Report, and was easily explained by means of Plate 5. If anything, 750° C. or 1,380° F. was rather below the temperature of the critical point Ar 2, as measured and indicated on the diagram, Plate 2; and all that could be said definitely, because there was always some amount of uncertainty in making experiments of this kind, was that this temperature was above the lower critical

(Dr. Alfred Stansfield.)

point Ar 1. For the present purpose this was all that was required; because when iron containing a certain amount of carbon was heated above Ar 1, which was a point occurring between 650° and 700° C. or 1,200° and 1,290° F., a certain amount of the iron went into solid solution with the carbon, and even at the temperature 690° C. or 1,270° F. became changed from α or soft iron, not merely into β or hard iron, but some of it into γ or plastic iron: so that at any temperature above 690° C. or 1,270° F. there was a certain amount of γ iron present, the amount of which depended simply on the percentage of carbon; and consequently there was free diffusion of the carbon in the iron up to an amount of 0·9 per cent. of carbon. The diagram of Professor Arnold's, Fig. 110, Plate 23, represented what might be called a solubility curve of carbon in iron, the vertical ordinates giving the temperature, and the horizontal abscissæ indicating the solubility of the carbon in the iron. Up to 700° C. or 1,290° F., or, as measured by Professor Arnold, up to 750° C. or 1,380° F., there was practically no carbon dissolving in the iron. About 700° or 750° C. (1,290° or 1,380° F.) the carbon dissolved to the extent of 0·9 per cent. Then the carbon did not increase much with a considerable rise of temperature, up to about 900° C. or 1,650° F.; and then it increased considerably at about this temperature. This was roughly what was seen from the curve in Plate 5. The horizontal line SP, which indicated the Ar 1 change, though perhaps not really extending quite so far to the left as to reach the zero ordinate denoting pure iron or ferrite, nevertheless came so close to it that its extremity P should be somewhere between 0·00 and 0·07 per cent. of carbon; because the critical point Ar 1 at 690° C. or 1,270° F. occurred in the cooling of iron containing 0·07 per cent. of carbon, but did not occur in the cooling of electro-iron. From this it followed that carbon was practically insoluble in iron at temperatures below 690° C. or 1,270° F. The solubility of the carbon in the iron at the temperature of 690° C. or 1,270° F. was indicated by the length of the line PS, and was about 0·8 or 0·9 per cent. of carbon. There was some uncertainty as to the exact position of the point S, as could be readily understood from the fact that the evolutions of heat along the lines OS and SE were too small

to allow of determining with exactness the point S at which they met. Moreover there was some difference in the position of the point, depending on the purity of the steel, that is, its freedom from other constituents, such as manganese.

Professor ARNOLD asked whether the solubility of carbon in iron involved the assumption that the carbon was present in the free state, or diffused through the iron as a carbide of iron.

Dr. STANSFIELD replied that no assumption was made as to this question; it was left open to be taken either way. From the point S in Plate 5 it would be noticed that the solubility of the cementite in steel progressed along the line SE; as the temperature rose it increased slowly, until at about 900° C. or 1,650° F. it increased more rapidly. This portion of Plate 5 might thus be considered to correspond roughly with Professor Arnold's Fig. 110, Plate 23; and he hoped therefore it would be sufficiently obvious that the latter was not in any way a contradiction of the views put forward in the Report. It had also been explained in the Report (page 50) that, when steel containing say 0·2 per cent. of carbon cooled down, although most of the iron, when it crossed the line GO, underwent a change from the γ or plastic state to the β or hard state, and subsequently from the β to the α or soft state, yet some of it remained in solid solution with the carbon, and continued in the γ or plastic state until it reached the line PS; and then parted with its carbon, and changed suddenly from the γ or plastic to the α or soft state.

Mr. ROBERT A. HADFIELD wrote that he heartily congratulated Sir William Roberts-Austen upon this fifth Report to the Alloys Research Committee, and could readily understand how great must have been the tax upon his time in carrying out the large number of experiments now described.

It was highly satisfactory to note in page 42 the admission that pure electrolytic iron did not possess adamantine hardness, and that any modification of the ordinary known physical properties of soft

(Mr. Robert A. Hadfield.)

iron was due to the presence of other elements, of which one was hydrogen. Having had several opportunities of examining probably the purest iron yet known, containing 99·98 per cent. of iron—produced by Dr. Hicks, Principal of University College, Sheffield, and his colleague, Mr. L. T. O'Shea—he had found that, whilst brittle and fairly stiff to the file, this product, after being heated to a low red, became soft and readily bent double, much like a specimen of soft copper. No reversal of its physical properties was then possible; whether quenched from high or low heats, and whether quickly or slowly, it still maintained its softness and ductility.

The statement in page 48, that steel contained more combined carbon than slowly cooled pig-iron, was one which he could not understand. There were several varieties of pig and cast-iron which contained much more combined carbon than steel, even though they were cooled slowly. White pig-iron was an example; and the carbon in white iron containing manganese remained most obstinately combined, even though annealed by the process used when preparing malleable cast-iron. In this latter instance there appeared to be practically no treatment which was capable of breaking down the intimate combination existing between the double carbide of iron and manganese.

As regarded the solution theory, he regretted his inability to accept it in the form in which it was presented in the Report. As Sir William Roberts-Austen had himself pointed out (Proceedings 1897, pages 36 and 70), full evidence was not yet available for substantiating the theory. It seemed desirable therefore to advance slowly enough in this direction, or there might be much to unlearn. It was with much pleasure that he noted Sir William's cordial reference to Professor Arnold's labours. Speaking for himself and for many in Sheffield, he could say that the work of the latter had proved of the greatest practical value.

Mr. C. Frewen Jenkin had been asked a year or two ago to examine microscopically a sample of burnt steel. It was a billet taken out of a furnace, which, as the steel makers stated, was burnt and was useless. On examination with the microscope he found it

looked almost exactly the same as Fig. 31, Plate 9, and was very like Fig. 29. It was clear that the percentage of carbon was here much too high. The steel maker had told him that, the steel being burnt, all the carbon would be burnt out; and as it had originally contained about 0·1 per cent. of carbon, he had been greatly puzzled when he found it now had obviously much more than 0·1 per cent. A separate billet was therefore cut in half, one half burnt, and the other half kept as it was; and he then examined the two under the microscope. The burnt half again showed a higher percentage of carbon than the unburnt half, and chemical analysis gave the same result: the carbon had increased in the burnt steel. The conclusion he came to was that in the furnace the iron had taken up carbon by cementation, and that the burnt nature of the steel must be due to the curious form in which the carbon was, which was not normal; and that in this condition the steel was unsuited to the methods of working it, which were adopted of course for the normal condition of carbon in the steel. This idea had been somewhat strengthened when he learnt that it was generally recognised that the percentage of carbon in the billet was usually found to be slightly higher than in the ingot from which the billet had been rolled. This higher percentage might also be due to the increase of carbon by cementation in the furnace. It might be of interest therefore if Sir William Roberts-Austen would give his explanation of these facts; and whether it agreed with his own or not, it might lead to practical use in showing how to treat burnt steel by some process which would bring it back again to its proper condition.

Sir William Roberts-Austen mentioned that the long cooling curve of electro-iron, shown in Plate 2, was not one absolutely continuous photographic record, but on account of the great length of the curve it had necessarily been taken in three divisions, which were marked "record No. 1–2–3." The rate of advance of the photographic plate was not quite the same in all three records, and that was why they had been distinguished. Practically however it was a continuous curve. In Plates 4 and 5 it should be understood

(Sir William Roberts-Austen.)

that, wherever dots or marks were seen along a visible or invisible vertical line, a curve had been taken of the nature of that shown in Plate 2. Thus for any particular variety of steel, containing say 1·75 or 1·8 per cent. of carbon, points of recalescence were found at different parts of the curve. The method of manipulation was not quite so easy as might be imagined from merely looking at the diagrams in Plates 2, 4, and 5 ; and a great many curves might have to be taken before one was obtained which was successful in all the points of recalescence. In justice therefore to the assistants who had so patiently and perseveringly carried out this work, it was only fair to point out that the work embodied in Plates 4 and 5 was really prodigious, because every vertical line along which dots or marks were seen meant that often six curves like that shown in Plate 2 had had to be taken, before one was obtained which was entirely successful.

In answer to Mr. Windsor Richards' question (page 70) as to whether different parts of a mass of steel showed the same micro-structure, he appealed to Plate 17, in which Figs. 76 and 78 were two photo-micrographs prepared from sections cut from the interior of the head and of the lower flange respectively, at the crop end of a rail. Figs. 77 and 79 showed metal cut from corresponding positions, as regarded the transverse section of the rail, but from a part ten feet nearer the centre of its length. It would be seen that, although the grain in the crop end was smaller than that ten feet nearer the centre of the rail, the general structure nevertheless corresponded closely ; the constituents were the same, and their distribution was the same, though the samples were taken from places ten feet apart. The comparative smallness of the grain in the crop end was due to its being more rapidly cooled than the other parts in the length of the rail.

With regard to the confusing number of constituents to be remembered (page 69), in slowly cooled steel there were practically only two "ites," ferrite and pearlite ; while quenched steel gave one other, Martensite. With singularly little trouble the appearance of these could easily be mastered ; and when once this was done, their presence could always be detected in any section.

The segregation of cementite mentioned by Mr. Stead (page 73–4) probably took place in all steels which were comparatively low in carbon: that is, steels in which the carbon was less than 0·5 per cent. In armour-plate and rail steel, which had been annealed for some time at a temperature of about 600° to 700° C. or 1,110° to 1,290° F., the carbide invariably appeared to be drawn together into more or less homogeneous patches, as seen in Fig. 81, Plate 18. Minute laminæ of carbide moreover generally appeared, disseminated throughout the mass. It was possible that in the thin sheets mentioned by Mr. Stead minute laminæ of Fe_3C were dissociated and the carbon oxidized, so that the finished plate consisted merely of a matrix of ferrite crystals containing little knots of cementite.

Rails with a large grain, he agreed with Mr. Stead (page 78), were much more liable to fracture than those having a small grain. In most rails, especially those low in carbon, the grain was smaller and the ratio of the ferrite to the pearlite much greater on the outer parts of the rail than in the interior. In the unworn external parts of the St. Neot's rail (page 77) the grain was small, and the ferrite considerably in excess of that in the interior. The presence of much manganese almost invariably caused the grain of a rail to be large; and it was well known that rails containing too much manganese were not trustworthy.

In answer to Professor Arnold's question whether the terms eutectic and cryo-hydrate meant the same thing (page 81), they might be regarded as synonymous if it were remembered that the term cryo-hydrate was now held to be inaccurate, as suggesting chemical combination. It was now admitted that the cryo-hydrate in the liquid brine (page 45) was certainly a eutectic mixture without any true combination. The word cryo-hydrate had been employed by Guthrie before this was known; it would be better to reject it in favour of the word eutectic. The eutectic of an alloy however was the same thing as the so-called cryo-hydrate of a saline solution.

As regarded the tenacity curves of carburized iron (page 83), the fact of importance was that the maximum strength occurred at the saturation point of carbon, that is, with about 0·9 per cent. of

(Sir William Roberts-Austen.)

carbon. On the exact degree of strength which could be obtained in carburized iron by the most approved methods of treatment, he was not careful to insist.

The terms Martensite, Austenite, Troostite, and Sorbite had on various occasions been explained* by Osmond, who had justified the existence of the constituents they represented.

As regarded diffusion of carbon in iron, it had been shown by Dr. Stansfield (page 89) that there need be no divergence of view. Professor Arnold's diagram shown in Fig. 110, Plate 23, was practically one of solubility of carbon in iron, and as such practically agreed with the curve shown in Plate 5. It was not yet known whether the carbon diffused as carbide, or as dissolved carbon, that is, as a solution of graphite in iron. Neither was it known how the carbon was dissolved. It should moreover be remembered that the solution of carbon in iron might under certain circumstances deposit the carbon either as graphite or as cementite. There was no evidence whatever of the existence of the hypothetical compound $Fe_{24}C$, which was simply the saturation point of iron by 0·89 per cent. of carbon, expressed as a compound; whereas it was really a eutectic without any molecular composition.

The views so long held by M. Osmond and himself as to the allotropy of iron he was glad to find were now widely accepted. Both of them anticipated that the new method of recording and obtaining the cooling curves would in the future be highly useful, especially in relation to the new hydrogen points of recalescence.

Electro-iron was not always of adamantine hardness, he agreed with Mr. Hadfield (page 91); but sometimes it was. If it was soft, this was merely because it had been deposited with an electric current of a particular current-density, and had come down in a state of fine segregation.

Mr. Jenkin's question as to means of restoring burnt steel to its normal condition (page 93) demanded further experiments before a complete answer could be given. Burning did not always mean removal of carbon, but was often due to change of structure arising from the temperature to which the metal had been raised.

* Roberts-Austen, "Introduction to the Study of Metallurgy," 1898.

In conclusion, he desired to thank the members for the warm reception they had given to the present Report. With regard to the written contributions to the discussion, he cordially thanked Professors Callendar, Ewing, and Ledebur, for their interesting and appreciative communications.

The President had much pleasure in informing the meeting that, in connection with the knighthood which had just been conferred by the Queen on the author of the Report, there was reason to believe that this honour had been "given for science"; Lord Salisbury it was hoped had himself seen the previous Reports of the Alloys Research Committee. The Members he was sure would all wish to join him in expressing the thanks of the Institution to Sir William for such a highly interesting and valuable piece of work as the present Report. The research work of the Institution had always been a special feature, ever since it was first entered upon. The Annual Report of the Council for the past year gave a summary of the various directions in which at the present time research work was proceeding; and the work of the Alloys Research Committee, which was conducted so ably by Sir William Roberts-Austen, was certainly not one of the least important of this valuable series of researches. The Council had yesterday had under consideration the question of the continuance of this Alloys Research; and had decided that the great value and promise of the results already obtained fully justified them in placing in the hands of the Alloys Research Committee and of its able experimentalist and investigator, Sir William Roberts-Austen, the means of proceeding yet further, in order to discover as much as possible of the interior structure of iron and steel. They were fully sensible of the great indebtedness the Institution was under to Sir William Roberts-Austen for so valuable a piece of work as the present Report, following upon the four others which he had previously prepared for the Institution. Not merely had this fifth Report conveyed to the Members so much information from his own work, but it had also been the means of bringing into the discussion much that had been interesting from other authorities, whom they were always glad to see present and to

(The President.)

listen to. Of these he might add that Mr. Stead had considerably abridged his remarks; and the Institution would therefore be happy to receive from him a still fuller exposition of his views, in the form of a separate paper as soon as he could prepare it.

Professor A. Ledebur, Freiberg, Saxony, wrote that he had read with great pleasure Sir William Roberts-Austen's present Report, and considered the results recorded therein denoted a fresh important advance in the knowledge of the subject under investigation. It had all along been his own conviction, which he had several times expressed, that the nature of alloys, and particularly of the iron-carbon alloys, would be better understood if they were considered as solutions which separated themselves only through their higher melting and congealing temperatures from the solutions that were liquid at ordinary temperatures. A further beautiful confirmation of this view was now furnished in the comparison drawn by Sir William Roberts-Austen between the behaviour of salt solution and that of liquid iron in congealing. The observations were new which were here recorded respecting the influence of occluded hydrogen upon the number and position of the critical points in the cooling curves of iron and steel; and further communications upon this subject would be eagerly looked for.

Professor Hugh L. Callendar wrote that he had followed the work of this research as closely as his absence in Canada during the last five years would permit. In devising the differential plan of observation described in the fourth Report (Proceedings 1897, page 63), and illustrated by the curve given in Plate 2, he had no doubt that Sir William Roberts-Austen had discovered the most sensitive and promising method hitherto developed for investigating these obscure but highly important changes, which occurred in the cooling of iron containing various impurities that exerted so marked an influence on its mechanical properties. By this means effects had been detected which would have been beyond the ken of any less

delicate method. The special advantage of employing the differential plan in the present instance was that it was not only extremely sensitive, but also peculiarly suited to the thermo-electric method of research. Recently he had himself had some experience in the application of a similar method with thermo-couples to an entirely different purpose: namely to the observation of the small cyclical changes of temperature which occurred in the superficial layers of the metal of a steam-engine cylinder (Proceedings Inst. C.E., vol. cxxxi, 1897, pages 147–268). The successful application of the thermo-electric method in that instance depended largely on the adoption of the differential plan; and it appeared to be even more peculiarly suited to the present investigation.

In page 51 the author had referred to some recent observations by Dr. Morris on changes in the magnetic permeability of iron about 600° C. or 1,100° F. Corresponding slight and peculiar deviations from the smooth parabolic curve had also been detected by the writer in the variation of the electrical resistance of pure and impure iron, which had been described in the Philosophical Transactions of the Royal Society, 1887, pages 201–3 and 226–9. These deviations appeared to take place at different temperatures in different specimens of iron; but no complete investigation or interpretation of them had hitherto been possible. It appeared likely that the new method of research would result in the explanation of their true significance.

With regard to the effect of gases dissolved in the metal, it was well known how remarkable an effect was produced in many cases by the presence of extremely minute quantities. It had been shown for instance by Mr. F. H. Pitcher, in some experiments conducted under the writer's direction at McGill College, Montreal, and communicated to the British Association in 1897 (Report, pages 763–6), that the magnetic hardness or "hysteresis" of commercial iron was greatly reduced, in some cases to less than one-third, by prolonged heating in a high vacuum, which had the effect of removing traces of occluded gases. The magnetic hardness was a quality of primary importance in the application of iron to all electrical purposes. The reduction of the hardness to one-third meant a large saving in power, especially in transformers. The elucidation of these peculiar low-temperature

(Professor Hugh L. Callendar.)

critical points, recently discovered in the cooling curves of iron, would no doubt have the effect of explaining and systematizing much that was at present empirical in the treatment of iron for electrical purposes. Another point that had recently been attracting a large share of interest in the electrical world was the magnetic deterioration of samples of iron under certain conditions at comparatively low temperatures. By the application of some such delicate method of research as that now proposed, it might well be found that this effect was connected with the occlusion of gas, or with some obscure molecular change, of which the conditions could now be more hopefully studied.

Having regard to the importance of fixing the exact limits of temperature at which these molecular changes occurred in irons of different composition, the writer was inclined to suggest that it would be an advantage if the experiments could be conducted on a slightly larger scale: say with masses of 50 grammes instead of 5 grammes, or 1·75 ounce instead of 0·175 ounce. It would then be possible to observe these changes under more favourable conditions, and to refer the temperature measurements directly to the platinum-resistance scale, which was more definite and more accurate than the thermo-couple scale, especially at low temperatures. It would also be of great interest to determine how far these changes were reversible with change of temperature; and whether they took place between the same limits on heating a specimen as on cooling it. This might perhaps be accomplished by the electrical method of heating, which rendered it possible to apply heat in a regular and continuous manner. The changes occurring in the tempering of steel at comparatively low temperatures might also receive further elucidation by the application of the new differential method to the inverse process of heating.

Professor J. A. EWING wrote to express his sense of the great value of Sir William Roberts-Austen's remarkable series of Reports to the Alloys Research Committee. Probably no one, who was not himself familiar with the difficulties of scientific research, could admire sufficiently the skill which had been brought to bear upon

the conduct of these experiments; or appreciate fully the immense amount of patient labour, of which these Reports were the outcome. The Institution was to be heartily congratulated on having work, so well worth doing, so admirably done. The Alloys Research Committee had shown their wisdom throughout in taking a wide view of their task, and in not attempting to narrow their enquiries down to points which might be held to be of immediate practical moment. In dealing with so large a subject as the nature and properties of alloys, it was essential to get at the general physical facts. The practical applications might well be left to follow in due course. The whole history of research went to show that it was impossible to say beforehand what would be the practical fruit of a physical enquiry. Points which at first sight seemed to have no more than a purely scientific interest had again and again proved to be fundamental in practical applications. The Alloys Research Committee were casting on the waters their bread of scientific knowledge, and he did not doubt that much of it would sooner or later contribute to the advance of engineering practice. The present Report dealt mainly with two distinct lines of investigation: in one, the changes of structure were traced during the cooling or heating of a metal, by recording the successive points at which there was evolution or absorption of heat; in the other, the microscope was applied directly to the examination of the structure. Sir William Roberts-Austen's devices for recording thermal change had been brought to a degree of perfection not before reached; and by this means new points of halt had been found in the cooling of electrolytic iron. As to the part probably played by hydrogen in these phenomena, his remarks were particularly interesting and suggestive. The importance of the microscope in metallurgical research was every day becoming more widely recognised. An engineer attempting the study of papers relating to this subject was at first somewhat bewildered by the terminology of the micrographers, finding himself confronted by many unfamiliar and forbidding "ites"; and perhaps the first impression derived from a casual glance at micro-photographs was that they were meaningless hieroglyphs. But when the matter was taken up seriously, and

(Professor J. A. Ewing.)

especially when specimens of iron and steel were actually observed under the microscope, the subject was at once found to be full of promise, and the hieroglyphs were seen to have a definite meaning. The tiny fragment of metal under examination was found to be truly representative of the mass from which it came, and to give a world of information regarding the composition and history of the mass. The ancient phrase *ex pede Herculem* might fairly be the motto for the student of micrometallurgy. To himself the study was comparatively a new one; but by his own experiments he was already more than convinced of its interest and value. In experiments made with one of his students, Mr. Walter Rosenhain, which had recently been communicated to the Royal Society (Proceedings, 16 March 1899, pages 85–90), he had found that the microscope threw a flood of unexpected light upon the nature of plastic yielding in metals. The Institution he trusted would continue, through the Alloys Research Committee, to enjoy the privilege of being responsible for Sir William Roberts-Austen's work.

MACHINERY FOR BOOK AND GENERAL PRINTING.

By Mr. WILLIAM POWRIE, *Member*, of London.

Until a comparatively recent period Typography was almost the only process employed in the production of books and other readable matter ; but it is now largely supplemented by lithography, collotypy, &c., each requiring special machinery and appliances for their effective development. In fact the operations in a modern printing factory are specialized and carried on in departments, in a similar way to work in an engineering establishment ; and a simple list of the various machines employed would fill several pages. As an excellent detailed description of a rotary newspaper-printing machine, and the method of producing a daily paper, has been given by Mr. John Jameson in the Proceedings of this Institution for 1881 (page 511), the author purposes dealing at present with the leading classes of Machines employed for Book and Job Printing.

Although the art and method of printing from movable types was invented about the beginning of the fifteenth century, it was not until the early part of the present century that printers' engineers and tool-makers began to produce power-driven machinery. Since then the improvement and development of printing machinery has been continuous, and more especially during the last thirty years, until the modern printing machine bears about the same comparison with the early ones that a first-class express locomotive does with the historic "Rocket;" and printers' engineering is now an important department of mechanical work. There is great diversity of details in the presses and machines used by typographic printers: some are of the "platen" kind, printing the whole surface of the sheet at once; and others are of the "cylinder" class, printing one line at a time, but

revolving so rapidly that their production exceeds that of the platens. Some have one cylinder for printing one side of the paper only; while others have two or more, and print both sides at one operation, either from rolls or in sheets as may be desired. But a few leading principles are common to them all.

The aim of the printer is to produce on paper in one or more colours a correct representation of a given arrangement of type, or combination of engraved blocks or ornamental designs, which, while being printed from, are usually wedged fast or "locked up" securely in iron frames called "chases," the whole collection being called a "forme." To this end it is necessary to provide apparatus for covering the printing surface of the forme with a thin even coat of the colour in which the work is to be printed; and other apparatus by which the colour is transferred to the paper, so as to be always in the same position on a sheet of given size. When these operations are performed separately by the workman, the apparatus is usually in this country called a "press"; and when they are performed automatically by apparatus actuated by the turning of a single shaft, the combination is termed a "machine"; but in some other countries every such apparatus is termed a press and the maker a press builder, while here we have both press and machine makers, usually termed printers' engineers.

Most newspapers and magazines of large circulation are printed from webs of paper brought to the machine in large rolls, printed on both sides and delivered in sheets; but the bulk of book and job printing is done on machines which print one side of the paper only at a single operation, the sheets being taken singly from a pile. In platen machines the paper is usually fed or laid on and taken off by hand. In cylinder machines the sheets are usually delivered automatically: some are also self-feeding, but hand-feeding is still a common practice.

Hand Press.— For general proving or for printing small editions the hand press is still largely used. The general arrangement is as represented in Fig. 1, Plate 24, and Figs. 3 and 4, Plate 25, where B is a sliding bed or carriage for supporting the type

forme; P is a platen for taking the impression, set down by a combination of levers L; and T is the tympan, and F the frisket frame, for holding the sheet in position while being printed. The forme is inked over by a hand roller, the sheet to be printed placed between the frisket and tympan, which are then folded down over the type; the carriage is slid under the platen, which is then pressed down on the paper by the levers with a force equal to about twelve tons in an average-size press, printing 36 inches by 24 inches.

Steam-driven machines were made on this principle thirty years ago, and largely used for book printing; but although they did good work they were slow, and the demand for greater speed has led to the development of cylinder machines, which, owing to the improvement in engineering tools and methods, can now be relied on to do quite as good work as the platens and a great deal more of it: so that platens have almost disappeared for large work, although the smaller varieties are used in increasing numbers for job printing.

Single-Cylinder Machines.—Wharfedale or single stop-cylinder machines have been for many years the most popular for book and job printing; their general arrangement is as shown in Figs. 5 to 11, Plates 26 to 29. In designing a machine of this class, the first thing to decide is the size of sheet it is to be capable of printing, and then how many inking rollers shall clear or pass over a full-size forme; these data determine the travel of the carriage, size of cylinder, and total length and width of the machine. The forme must clear the cylinder grippers at one end and the last inking roller at the other, while the circumference of the cylinder must coincide with the stroke or travel of the carriage, and the length of the forme over the chase settles the width of the machine. As it is usual to put the crank-pin in the driving wheels, the length of stroke required determines their diameter; and they in turn fix the height of the carriage, the ink-table having to pass over the top of them. The other working parts are arranged as the experience of the designer may suggest, and the frame is made to suit his arrangements. The frame is on the box principle, with two sides,

two ends, and one or more cross stays in the centre: all securely held together by tight-fitting bolts.

The carriage which supports the forme and ink-table, Plate 27, runs forward and backward on two, and in large machines on four, sets of anti-friction live rollers or bowls R, running on rails or tracks, which are usually planed after being bolted in position, in order to ensure accuracy. These rollers are kept at regular distances apart by coupling-bars on each side of them, Plate 28, and are compelled to run at the proper speed by being coupled to the rack-wheel shaft. The carriage is propelled by the rack or traverse wheels W, which are fitted with smooth flanges to run on rails fixed securely to the frame, and gear simultaneously into racks both top and bottom; the bottom racks are fastened to the rails, while those on the top are secured to the underside of the carriage. The rack-wheel shaft is coupled by a connecting-rod to a crank-pin in the main driving-wheels, and with its wheels runs forward and backward as the driving wheels revolve; the racks on the carriage compel the latter to move in the same direction through twice the distance. The printing cylinder is driven by the carriage, which has a toothed rack at each side, driving spur wheels on the cylinder ends. One of these wheels is securely fastened to the cylinder, while the other runs loose when the cylinder is at rest, the fast wheel having a portion of its teeth planed off at the underside to clear the carriage rack on the return stroke. The loose wheel is coupled to the cylinder by a pawl clutch, Figs. 8 and 9, Plate 29, so arranged that it allows the wheel to run either loose or securely attached to the cylinder as required; and an automatic cylinder-check and double-rolling motion D are fitted, which when required prevent the pawl from dropping into position to take the cylinder through each alternate revolution, so that the forme then gets twice the usual amount of inking. Moreover, by touching a small lever, the attendant can at will prevent the cylinder from revolving. At each end of the cylinder surface, a belt of about $1\frac{1}{2}$ inch width is made exactly the diameter of the pitch line of the cylinder wheels: so that these belts will roll without slip upon the bearers which are secured on the carriage. The centre part of the cylinder, being the printing surface, is made 1–16th inch smaller in diameter than the end belts, in order

to allow space for a few sheets of paper and a calico covering, for holding the overlays or patchwork " make-ready " ; the latter is required to make up for the uneven surface of the forme, and to bring up the printing properly on the paper. The cylinder surface is ground dead true after turning.

The strain of the pressure required in printing comes principally upon the cylinder and the frame cross-stay S immediately under it, as the carriage and forme are like a fine wedge driven in between these to separate them. The cylinder is stiffened by ribs cast inside, and has a strong steel shaft right through, Plate 28 ; while the centre cross-stay is stiffened by a heavy bottom flange, Plate 27, and rests, as do the other stays, on planed seatings projecting inwards from the frame sides. The bolts are thus relieved from pressure, and have only to hold the parts together.

The ink, which is usually made of lampblack or other colouring matter, is ground up in boiled or blazed linseed oil, contained in a narrow trough, called the ink-box, duct, or fountain, Plate 27, placed across the back end of the machine; one side of the box is formed by a cast-iron roller called the ink-cylinder, and the other by a triangular piece of cast-iron called the duct-knife, which is really a scraper. The ends of the ink-box are plates, fastened by screws to the ends of the knife, and lapping over shoulders turned on each end of the ink-cylinder to prevent the colour from escaping. The duct-knife is adjustable by screws in its back edge, and can be set close to the ink-cylinder or at any required distance from it, so that the latter may be coated with colour to any thickness desired. The colour is taken off the ink-cylinder by a small vibrating composition-roller, and is laid on the ink-table or distributing-drum according to the class of machine. An adjustable ratchet-motion causes the ink-cylinder to revolve when the duct roller is in contact with it, whereby a portion of its coat of colour is transferred to the duct roller, and over more or less of its surface as required. The distributing drum revolves in contact with two or three composition-rollers placed on the top side of its circumference, and is compelled to move endways a few inches to and fro by a lever and cam or by a worm-wheel and crank; the result of this lateral movement

combined with its rotation is to spread the colour in an even thin film all over its surface. Underneath the drum is another vibrating roller, which takes colour from the drum and deposits it on the ink-table or "slab." The latter is an iron plate secured upon the end of the carriage; its top surface is finished quite smooth, and is set to the same height as the face of the forme. In machines for the commoner sorts of printing, the colour is transferred from the ink-cylinder to the ink-table direct, without passing over a distributing-drum, which is omitted from such machines. The ink-table moves forward and backward under the rollers, and has the colour equalised over its surface by the distributing rollers or "distributors," which are caused to traverse laterally over its surface by being placed diagonally across the machine. The forme rollers or "inkers" take up a coating of colour from the ink-table as it passes under them; and this coating is further distributed or equalized by the "traversing riders," Plates 27 and 29, which are made of steel tube accurately turned and polished, and are compelled to move endways to and fro by a suitable crank-motion. The colour is ultimately deposited by the inkers on the face of the forme; and finally by the pressure of the cylinder is transferred to the paper to be printed. The whole of the inking and distributing rollers are made of steel tube, with ends welded in, and covered outside along the centre portion with a composition made of a mixture of glue and treacle or glycerine, cast hot in accurately bored and polished moulds.

In order to produce good printing, especially if the design is in several colours, it is necessary that the cylinder and carriage should always come into contact in exactly the same relative position, and that the cylinder start and stop at exactly the same place in each revolution. When the carriage is made a good sliding fit in the frame, and the cylinder fits its bearings so that there is no end play, and the teeth of the wheels and racks are of correct size and shape, and when also the bearers are the proper height and in contact with the cylinder belts when in motion, then the carriage and cylinder will move so accurately that the cylinder may be run repeatedly over the forme without showing more than a single impression. When the sheets to be printed are laid against stops on the "grippers," the above is sufficient

to ensure good "register;" but in the machines now described the stops or "lays" are usually attached to the feed-board, and are quite unconnected with the cylinder, so that any variation in the position of the cylinder, when the grippers close on the sheet, spoils the register. To prevent such an occurrence, these machines are fitted with a pushing motion, which presses the cylinder back to a dead stop before the grippers close on the sheet, Plate 28, and Figs. 10 and 11, Plate 29. On the inner side of the brake-wheel rim is cast or fastened a projecting lug A, which is fitted to fill the space between two movable levers B and C, so arranged that, when the cylinder revolves in the direction of the arrow, the projection A on the brake wheel depresses the front lever B, Fig. 11, and passes clear over it, allowing the lever to rise up to its previous position. When the cylinder stops, the other lever C, which has been drawn back for allowing the wheel to pass, Fig. 11, is pressed forward by a cam and lever arrangement, and pushes the brake wheel and cylinder back, until the projection A on the wheel is hard up against the front lever B, Fig. 10.

The sheets to be printed are laid in a pile on the front part of the feed-table. They are removed by the operator singly to the back portion, and laid in contact with the "lays" at the gripper edge and at one side. This portion of the table is hinged at its front edge, and the back edge is raised by a cam and lever arrangement until the sheet is in contact with the gripper edge of the cylinder; the grippers then close on it, the cylinder revolves, and the printing is completed.

In the early days of cylinder printing-machines, the sheets when printed were removed by hand from the cylinder, and deposited in a neat pile on the delivery table with the printed side up. The boy or girl attendant usually transported the sheet with a rapid movement through the air, which caused it to float down on to the pile upon the table. This came to be termed flying the sheet; and the mechanical apparatus which has now generally replaced the human attendant is called a "flyer," Plate 27, and Fig. 10, Plate 29. A cylinder of wood, half the diameter of the printing cylinder, and provided with grippers to alternate with those of the latter, is placed in a convenient position and geared with the printing cylinder; cams for actuating

both sets of grippers are so arranged that, when they are passing the plane in which lie the axes of both cylinders, the main grippers open and the flyer grippers close on the sheet, Fig. 10, which is then carried round the small cylinder until the latter stops and the grippers are opened, when the sheet is in position between two or more rubber-coated rollers, which are adjusted on a spindle to suit the unprinted margins of the paper. These rollers apply sufficient pressure to retain the sheet in position and compel it to move onwards when the flyer cylinder makes the next revolution; but, instead of going round with the cylinder, the paper passes off upon a series of carrying tapes, which are put in motion by the flyer cylinder, and at the proper time is lifted by the "fan," which may be likened to a large oblong hand, with wooden laths instead of fingers. The fan transfers the sheet to the pile on the delivery-table, turning it upside down on the way, and so delivering it with the printed side up. In order to facilitate "making ready," the flyer apparatus is so arranged that, by depressing a lever, it may be elevated bodily for giving ready access to the cylinder, as shown by the dotted lines in Plate 27. Automatic delivery is now the rule, but automatic feeding is still the exception; and although some highly ingenious apparatus has been tried, and in certain cases found to answer well, yet the great diversity of circumstances under which printing machines are used, and the variety of papers printed, make the production of a satisfactory feeder at a moderate price a difficult problem to solve. Considering the number of clever minds that have been and are devoting attention to it, and the stimulus of stringent factory regulations, the time is probably not far distant when automatic feeding will be as common as automatic flying; and a pile of plain paper deposited on the feeder table will be printed and deposited in a pile at the delivery end of the machine, without being touched by hand.

The class of machine just described, with various modifications of detail, has enjoyed a great popularity among British printers during the last twenty-five years, as a good all-round machine; but, for printing illustrations or work with solid masses of colour, the inking is not satisfactory. Although this has been remedied to some extent by double rolling, or placing inking apparatus

at both ends of the machine, these methods reduce the speed and rate of production.

Fine-Art Machines.—Within the last few years the preparation of printing blocks by photographic processes has so reduced their cost, that books and magazines are now more plentifully illustrated; and the demand for a better kind of printing machine has become imperative. Plates 30 to 32 represent some of the fine-art machines now coming into favour for this class of printing. These machines are substantially built. The defective inking of the Wharfedale machine, Plate 27, arises from the forme rollers receiving colour only when the ink-slab runs under them; and this intermittent supply, although sufficient for open type, soon gets exhausted when large surfaces have to be covered, and the rollers are almost bare before they have gone over the forme twice. In Plate 32 the flat distributing-slab or table is replaced by cylinders in contact with the forme rollers, ensuring a continuous and even supply of colour to the forme, which enables the machine to be worked to its utmost capacity. The sheets are fed in at the top of the cylinder to lays attached to it, as shown in Fig. 15, Plate 33; and the lays are adjustable by screws, which greatly facilitates obtaining correct register. By dispensing with the ink-table and placing the inking apparatus nearer to the cylinder, it is easier to put the forme into position on the carriage, and to get at it for cleaning and adjustment.

To facilitate changing and cleaning the inking rollers, they are divided into two sets, Plate 32; and by a rack and pinion arrangement the ink-box and distributing rollers can be moved backwards bodily on the frame, leaving the forme rollers more accessible to the operator, as shown in Plate 31.

The flyer apparatus can also be detached and moved away from the cylinder to facilitate "making ready," Plate 31; and the flyer drum, instead of being a hollow cylinder of wood, is a series of gun-metal rings with grippers attached, the rings being fixed on a shaft. This arrangement is less liable to get out of truth, and makes less noise in working, than the hollow wooden drum.

To ensure smooth running at the increased speed now required, these machines, as well as the best of those previously described, are fitted with air-buffers, which take up the momentum of the reciprocating carriage and give it an impulse to return, Plates 27 and 32. (*See also* page 120.)

Two-Revolution Machines.—In the last two machines, which are of the stop-cylinder class, the cylinder stops after each impression, and remains at rest until the carriage has returned to the original starting position. But the desire for increased speed has led to the introduction of two-revolution machines, in which the cylinder is continually in motion while the machine is at work, and makes two revolutions for each sheet printed, as shown in Plates 34 to 36. Although this class of machine was in use in this country over twenty-six years ago, it met with little favour until quite recently, when introduced in an improved form as a novelty from the United States.

The type carriage in these machines is propelled in several different ways; but the arrangement shown in Plate 36 seems to have found most favour up to the present with British printers. Instead of the rack-wheel travelling forward and backward while in gear simultaneously with both the top and bottom racks, as in the machines previously described, it revolves continuously in one direction, and being mounted on a sort of cradle-frame A has a small vertical movement, which allows it to engage alternately with the top and bottom rack. Attached to the under side of the type carriage is a rectangular frame B, carrying the driving racks; and near their ends are two vertical flaps or shutters C turning on vertical pivots, which are opened and shut transversely at the proper times by the bowls or rollers D D and cam plate E. As the end of the frame B nears the rack-wheel, the shutter C opens, and allows the bowl F, carried by the rack-wheel, to pass it and get into the slot formed by the end of the frame and the edge of the shutter, which has now closed. Then the rack-wheel moves away from the rack it is driving, and the bowl F takes charge until it comes round to the bottom of the slot, when the rack-wheel engages with the

other rack, the shutter opens, and the carriage proceeds on the return journey. These movements are repeated at each end of the stroke.

As this method of driving gives an even steady speed of travel, with only a short stay at the ends, the momentum of the carriage is considerable, and is taken up at each end of the frame by the air-buffers, Plate 36, which soften the shock at the ends of the stroke, and give the carriage an impulse for its return. The cylinder is not driven by the carriage, as in the machines previously described, but by independent gearing from the driving shaft, whereby a smooth steady motion is produced; and in order to ensure accurate register, a few teeth on the cylinder and type carriage engage with each other when the printing surface is about to meet the forme. The sheets are fed in to the top of the cylinder as in the fine-art machines; but the lays are attached to the frame, and are removed out of the way when the grippers seize the sheet, which is carried round by the cylinder, printed, and delivered by a flyer in the usual way.

The inking arrangements of these machines are generally similar to those of the stop-cylinder machines; but the distributors are arranged in pairs, with a polished steel-tube roller between, geared to run continuously, which materially assists the distribution of the colour. During the printing, the cylinder is pressed down and held in contact with the forme by a pair of toggles or eccentrics E, Fig. 16, Plate 33; and, when the forme has passed under it, the eccentrics are released, and the cylinder is raised about a quarter of an inch by helical springs at the top of the impression rods RR, in order to clear the forme during its return stroke. The bowl B, carried at the end of an arm A which turns loose upon the eccentric shaft E, runs in the groove of the impression cam C, which revolves in the direction of the arrow. On the spindle of the bowl is centred a quadrantal jaw-lever J, having on its underside a jaw engaging the impression arm I which is fixed upon the eccentric shaft E. In the jaw lever is fixed a pin P, which works in a quadrantal slot in the check lever K, keeping the jaw engaged with the arm I while both move together through nearly a quadrant of a circle and back during each revolution of the cam C, thereby rotating the eccentrics E through the same angle forwards and backwards for applying the

pressure upon the forme and relieving it again. When it is desired to miss printing without stopping the machine, the cylinder is retained in its highest position by disengaging the jaw lever J by means of the foot lever F, which is depressed by the treadle T at the feeder's stand. The check lever K and the jaw lever J are thereby raised into the positions shown by the dotted lines: so that, while the impression cam C continues to revolve, the jaw lever J works clear of the impression arm I, and the eccentrics E are not brought into action for depressing the cylinder. The treadle T is held down as long as required by the pin N catching underneath the foot board; when this is released by pushing it aside with the foot, the treadle and foot lever F are raised to their original position by the helical spring S. The jaw lever J then drops into gear again with the impression arm I.

Two-Colour Machines.—The machines previously described are designed as single-colour machines, although two or more colours may be printed on them at the same time with special appliances; but where much work in colours is done, such as posters, showcards, labels, &c., it is preferable to employ two-colour machines, as represented in Plate 37. These are designed on the same general principles as the single-colour machines represented in Plate 26, but are double-ended, and the cylinder revolves twice for each complete impression. The carriage is double, having space in the centre for two formes; and an ink-slab is fixed at each end. The inking arrangements are similar to those on the single-colour machine; there is a complete set at each end, and for each colour in the printing. The formes are inked up by passing under the inking rollers, as in the stop-cylinder machines; and the cylinder with the sheet of paper to be printed rolls over both formes before it stops; thus a two-colour impression is obtained at each travel of the carriage. The sheets are fed in and delivered as in the single-colour machine; and if more than two colours are required in the design, the sheets can be put through the machine as often as required, and completed as in the other machines, with the advantage of having two colours put on at each printing. If two-colour work falls off, such

a machine can be used as a single-colour machine; but the production will be less, because owing to its greater length it cannot be worked at the same speed.

Perfecting Machines.—The first successful cylinder printing machine, which printed the issue of "The Times" for 29th November 1814 for the first time by steam power, printed the paper only on one side in a single passage through it, being what is called a single-side machine, although it had two cylinders; but the necessities of newspaper and book printers soon led to the introduction of machines which "perfect" or print both sides of the sheet in each complete revolution, and are known as "perfectors."

These machines differ in their arrangements and details, but may be grouped generally in two classes: those with large cylinders making one revolution; and those with small cylinders making two revolutions for each sheet printed. They are used for book and magazine printing, where the editions are large and the sheets have to be printed on both sides. The machines mostly in favour with British printers for ordinary work are those with the large cylinders, of which Plate 38 shows the general arrangement, and Plate 39 is a sectional view showing the arrangement of the cylinders, and of the tapes which guide the sheets through. The type carriage is here driven by a horizontal pinion, Plate 39, secured to the top of a vertical spindle, and acting on a rack with two flat sides and round ends, which is secured to the type carriage, but is free to move transversely: so that the pinion may gear into each side of the rack alternately, and cause the carriage to move first to one end and then to the other. Each type-forme comes under its own cylinder, and the sheet of paper is printed first on one side and then on the other.

The cylinders run in fixed bearings adjustable vertically to suit the impression, and the registering drum is also adjustable vertically, so as to vary the length of the tapes between the inner and outer forme-cylinders, and also to alter the position of the sheet on the latter while being printed, in order to ensure the pages being exactly opposite each other on both sides of the paper. The printing surfaces of the cylinders are covered, as in the single-cylinder machines, with calico for the

"overlays" and a few sheets of paper or a blanket, according to the class of work and the result required; the remaining portion of their circumference is made about $\frac{1}{4}$ inch less in radius, so as to clear the formes during their return. The sheets to be printed are laid in a pile on the feed-table, which is a fixture, and are fanned out at the front: so that the feeder has but a small distance to move them, and usually "strokes" them down to the front lay marks with a hard wood or bone stroker. The gripper drum, which is about one-third the diameter of the printing cylinders, opens its grippers each alternate revolution. These seize the sheet by the front edge, and draw it forward into the tapes; then the grippers open, and the sheet held between the two sets of tapes is carried round the cylinders until it is printed on both sides, and deposited on the receiving table. The inking arrangements are similar to those on the two-colour stop-cylinder machine, as there is an ink-box or duct, with ink-table, distributing, and inking rollers, at each end of the machine, one set for each forme.

In these machines as usually constructed, only two inking rollers clear a full-size forme, which is not sufficient for good illustrated work; but the inking may be improved by applying a continuous inking arrangement similar to that shown on the fine-art machine, Plate 32. Flyers are now also frequently attached for delivering the printed sheets, and air-buffers for softening the shock of the type carriage at the end of each stroke.

In the small-cylinder two-revolution class of "perfectors" the cylinder bearings are fixed at both sides to slides, which move vertically for raising the cylinders above the formes during the return of the type carriage. The slides are held down by powerful knee-joints while the cylinder is in contact with the forme printing the sheet, and are raised by springs, as in the single-cylinder machine. The cylinders are placed close together, and both are fitted with grippers; those on the first or "inner" cylinder take charge of the sheet until after it is printed on the first side, when the "outer" cylinder grippers take charge until the second side is printed; after which the sheet is shot out upon the receiving table or delivered by a flyer, according as the machine may be arranged.

The type carriage is propelled sometimes by an upright spindle and horizontal rack, similar to the arrangement in the single-revolution perfectors, Plate 39 ; but more frequently by a vertical rack securely fastened to its under side, and driven by a pinion on a horizontal shaft with a universal joint, so arranged that the pinion gears into the top side of the rack-teeth during the travel one way, and into the under side during the return: this arrangement is usually termed the "mangle motion," owing to its early use in propelling horizontal mangles for smoothing cloth. Other methods are also in use, such as that for driving the carriage of the two-revolution single-cylinder machine shown in Plate 36; but the vertical rack in some form is in most favour, because the carriage can then be better supported near the centre to resist the pressure of the cylinder on the forme.

These machines have inking arrangements generally similar to the others, but are usually made with four inkers or forme rollers to clear a full-size forme; this, together with the greater stiffness of the carriage in the centre, makes them better suited for printing illustrated work. They are usually not run at so high a speed as the large-cylinder single-revolution machines; and they are so arranged that "set off" sheets can be fed in, to prevent the ink on the first side printed from "setting off" upon the second cylinder or adhering to it and smearing the next sheet.

Platen Machines.—Most of the small job printing is now done on platen machines, of which there is a great variety, although the leading principles are common to all ; and Fig. 2, Plate 24, may be taken as representative of the class. The body of the machine is a strong box-casting, as shown in the section, Fig. 23, Plate 40, with bearings for the shafts, and seatings for the brackets carrying the outstanding parts. The forme is secured by a spring clip in a recess V, which has been finished to a smooth accurate surface ; and, instead of its moving horizontally under the inking rollers as in the cylinder machines, the rollers pass down and up over it. The colour is put into the ink-box I, which is adjustable by screws ; and is transferred by the roller D to the circular ink-plate S. The latter is moved round

a little at each impression by a ratchet and pawl motion, so as to distribute the colour equally over its surface. The three rollers R act both as distributors and as forme rollers; for when they pass over the ink-plate they equalize the coat of colour on its surface, as well as take on themselves a coat to be transferred to the face of the forme. Below the forme there is an extra distributor plate P, which receives colour from the same rollers R, distributes it by a traversing movement, and restores it to the rollers, so that they can give a fresh touch to the bare places of the forme on their way up again.

In the working of platen machines the sheets of paper are usually both laid on and taken off by hand. The operator takes a blank sheet from the pile on the table with his right hand, and lays it up to the gauge-pins or "lays" while the platen is at rest in the position shown; and removes the printed sheet with his left hand, after the platen has brought it into contact with the forme and has returned to its first position.

The platen, which is finished to an accurately smooth surface, rests on wedges B fitted into the platen back. The wedges are adjustable by screws, as shown in Fig. 24, so that any side or corner of the platen can be advanced as may be required, in order to give an equal impression all over the surface of the forme. The face of the platen is covered with a thin cloth or a few sheets of paper, or both, as is the printing surface of the cylinders of the other machines; and is "made ready" in the same way, by pasting pieces of paper opposite the low places of the forme, so that the impression may be of equal depth all over. The sheets are strained tight, and held in position by clips C at each side of the platen. The lays are attached to the platen covering; and the sheet to be printed is held in position and removed from the face of the forme by two thin pieces of steel F, called frisket fingers. When the platen is moving forward, these come down and press on the end margins of the sheet; and when the platen is returning to the feeding position, they are raised to release the sheet. The platen is balanced by long helical springs; and the pressure upon it while taking the impression is intensified by a toggle-lever arrangement T, so that in an average size machine,

printing sheets 18 inches by 12 inches, the pressure will amount to about 20 tons when printing solid formes.

In platen as in cylinder machines it is sometimes desirable to prevent printing without stopping the machine. For this purpose, instead of compelling the platen to remain at rest, as the cylinders do, a "throw-off" arrangement is provided, Fig. 24, which sets back the wedges, and allows the platen to recede about a quarter of an inch, thus preventing the paper from coming in contact with the forme. This throw-off arrangement is used to prevent spoiling a sheet when not laid correctly, or to give double rolling when required; but when the bulk of the work is heavy, it is much better to provide machines with ample rolling power, so as to keep up the rate of production.

Printing on Dry Paper.—The strength of machines has been increased, in consequence of the change from printing on damp paper, which was customary twenty years ago, to printing on dry paper without leaving any marks of impression on the back, which is more general now. Also the profusion of illustrations produced from flat-surface process-blocks demands greater accuracy in the surfaces and adjustments of the printing machines than was previously considered necessary. The older presses and machines, designed to print with a blanket between the cylinder or platen surface and the paper, produced with careful management fairly good printing; but it was frequently so much embossed as to resemble books for the blind, and the sheets had to be pressed or rolled afterwards to make them flat. The modern machines, using a few sheets of hard paper instead of a blanket, turn out flat work without any sign of impression on the back.

Working Pressure.—A common working pressure in a lithographic printing-machine, working stones or flat metal plates, is about 200 lbs. per inch width of impression, and the line of pressure is not more than $\frac{1}{4}$ inch broad. The pressure per square inch of surface printed is therefore about 800 lbs. In typographic formes with illustrations, from a quarter to half the surface in contact with the cylinder or platen will be under pressure at the same time: so that, in order to obtain

the same result, the pressure will be 200 to 400 lbs. per square inch. The old "Albion" press, with a leverage of 200 to 1, and a maximum pull on the handle of 200 lbs., subject to an allowance of one-fifth for friction of parts and resistance of spring, gave only 53 lbs. pressure per square inch on the forme, which is inadequate for present requirements. Many of the older platen and cylinder machines gave similar results. One popular job platen, with a leverage of 150 to 1 and a maximum pull at the fly-wheel rim of 50 lbs., gives only 58 lbs. per square inch effective pressure on the forme. The job platens described in this paper with a leverage of 400 or 480 to 1, according to size, and a maximum pull at the fly-wheel rim of 80 to 90 lbs., give an effective pressure on the forme of 200 to 400 lbs. per square inch; and both these and the cylinder machines are quite equal to a pressure of twice that amount if required, for exceptionally heavy work.

Grinding of Surfaces.—The grinding of the cylinder surface dead true, as also of the bowls or live rollers under the type carriage of cylinder machines, which is now done where first-rate work is turned out, is found to be a great improvement for printing from fine process-blocks, where a single thickness of tissue paper may make all the difference between first and second-class printing.

Air Buffers.—As previously described, high-speed reciprocating flat-bed machines are frequently fitted with some provision for cushioning the momentum of the type-carriage and its connections at each end of the stroke. Springs having been found unreliable for this purpose, air-buffers are now coming more into favour, Plates 27, 32, and 36. With these it is easy to adjust the resistance to the speed and moving weight; they are not liable to get out of order, and they effect a notable improvement in smoothness of running, especially in machines having the carriage propelled at a uniform speed and turning the ends quickly. A quad demy two-revolution machine, running at 1,500 impressions per hour, may serve as an example of the need for cushioning. The type carriage, with its apparatus and a type forme, weighs about 14 cwts., and travels at about $4\frac{1}{2}$ feet per second: so that the momentum at the end of the stroke is about equal to 3 tons moving at one foot per second,

which, if not cushioned, would produce a blow on the propelling gear and framing at each end of the stroke or travel. In the machine under consideration the shock is taken up by two air-buffers at each end, 5 inches in diameter, with cylinders 15 inches deep, into which the pistons enter 12 inches, and produce a maximum air-pressure of 50 to 60 lbs. per square inch, equal to a resistance of about 2,000 lbs. at each end. As this is an increasing resistance through the last 12 inches of travel, the carriage is stopped smoothly, and receives considerable impulse for the return.

As the variety of work and the size of the editions, or the numbers of similar sheets printed, have greatly increased during the last twenty years, there is now more scope for special machines designed for special work. But the principal demand is still for generally useful all-round machines; and those now described may be taken as fairly representing the machinery employed for book and general or job printing in British factories at the present time.

Discussion.

Mr. POWRIE exhibited one of the platen job-printing machines, Fig. 2, Plate 24, and showed its action in working. Also specimens of the composition used for covering the inking and distributing rollers (page 108); and of the accurately bored and polished moulds for covering with the composition the steel tube forming the body of the rollers; and of the rollers so covered. Also specimens of printing from the following machines:—platen, Wharfedale stop-cylinder, fine-art stop-cylinder, two-revolution single-cylinder, and Wharfedale two-colour.

Mr. JOHN SOUTHWARD said that, as a printer and not an engineer, he had listened to the paper with the greatest interest, and had derived a great deal of instruction from it. Apart from its value as a comprehensive and accurate review of the best kinds of printing

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machines which printed from types on a flat bed, he thought it would be of service to the printing industry by bringing this subject before a body of mechanical engineers, because he believed there were few industries which had been so much overlooked by engineers as that of printing. For a great many years so few practical improvements had been made in printing machines in this country that foreign manufacturers had got ahead of English makers in many ways. Naturally printing-machine manufacturers would say that they provided as good machines as were called for, and that they must conduct their business on a commercial basis, and that better machines had not been provided because they were not in demand. Similarly printers also might say that there was not a public demand for such high-class work as would require improved machinery ; and it must be confessed that the general kind of printing which was done by the machines described in the paper had always been in a backward state in this country. On looking back at the report of the jurors of the Great Exhibition in 1851, it would be found that an international jury had then been compelled to call attention to the inferiority of English printing. At the next Exhibition in 1862 a Frenchman, M. J. C. Derriey, came over to London with some remarkable specimens of type founding, and showed that there were many possibilities in plain and ornamental type-founding which were really not believed or realised at that time. His improvements found little acceptance in England then, perhaps hardly any; but they were taken up abroad. The extraordinary effects which he had produced were imitated in Germany, and still more largely in America; and they laid the foundation of the superiority of American type-founding, which some printers thought was maintained to the present day. At any rate English printers did not avail themselves then of the Derriey types, and did not improve their class of printing. Coming sixteen years later to the Paris Exhibition in 1878, it was found that the Americans had meanwhile made marvellous strides forward, in regard both to type-founding and to printing machinery. A model printing office was put up in the 1878 Exhibition, which no doubt had surprised many of the visitors. In 1883 there was an exhibition of printing in the Agricultural Hall, Islington, London, at which he had been

one of the jury; and the inferiority of English printing was demonstrated. Perhaps the only piece of really fine printing in that exhibition was the one which gained the first prize. It was done in fifty-three workings; every sheet of print had to go through the press fifty-three times. In 1889 an international exhibition of printing was held at Stationers' Hall in London; and the English specimens of general printing were still inferior, as was acknowledged by the Lord Mayor, who presided, and by Mr. now Sir Henry Bemrose. In 1889 there was again another exhibition, showing that English printers had not even yet made much progress in fine printing. Within the last ten years however improvements had been made in machinery, which printers had really been compelled to adopt. The method of making photographic blocks had largely affected the modes of printing, and had necessitated extensive modifications in many of the machines. The fine-art platen and cylinder machines described in the paper would hardly have been adopted, if half-tone blocks had not been invented; because half-tone blocks required better inking and heavier pressure. As had been plainly shown by the author, one of the great faults of earlier printing machines was that they did not exert pressure enough; and in some of the fine-art machines the inking had since been greatly improved. Having himself been engaged for so many years in connection with the art of printing, he had no idea of depreciating it, but only of suggesting that mechanical engineers in general, as distinguished from printing-machine manufacturers, should pay more attention to the subject. There were many excellent printers' engineering firms, who could turn out unexceptionable printing machinery to meet the general demand as it arose; but he did not know of any trade whose improvement had been less completely promoted than that of printers. In London there was an important and influential Association of Master Printers and Kindred Trades, comprising some of the most eminent firms, which in its corporate capacity had sent out on 29th May 1897 the following appeal:—

"The Committee have observed with regret the great increase in the amount of foreign-made machinery used in connection with the printing trades; and they have decided to draw the attention of

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English printing engineers to this, with a view to finding a remedy, if possible, for so unsatisfactory a state of affairs. In their opinion the increasing preponderance of foreign machines used in the printing trade is due to the greater inventive and administrative ability which foreign printers' engineers display; and as the interests of the English printers' engineers are identical with those of the master printers, the Committee desire to ask whether something cannot be done for enabling printers to place in this country their orders for first-class machinery up to date, instead of having unwillingly to send them abroad." This appeal would serve to show that printers had complained that engineers had not provided them with exactly the machines which were wanted; and also to show that it would be a fine field of enterprise if scientific engineers would devote their attention to printing machinery more than they had hitherto done.

Mr. Alexander North fully agreed with the statement in the last sentence of the paper, that the principal demand was still for generally useful all-round machines. There was no doubt that most printers needed a machine which could be used for any and every ordinary purpose. As to automatic feeding (page 110), if engineers could supply printers with a reliable self-feeding apparatus, there was no doubt that in the course of a few years it would be used all through the printing trade. To produce such an apparatus which would work efficiently, a great deal of time and attention would have to be bestowed upon it. Whenever it was successfully matured, there would be a great demand for it. As far as he was himself concerned with printing, he should be glad indeed to see such a contrivance; and as soon as ever an effective self-feeding apparatus was brought out, he would be one of the first to examine its merits.

Mr. Powrie thought that, as regarded lack of enterprise (page 122) on the part of engineers in supplying printers with improved machinery, if it had been possible for printers to be a little less anxious about price and more anxious about quality, perhaps they might have been better served by engineers. It had given him great pleasure to prepare the paper, which might have been extended

to much greater length without by any means exhausting the subject. In its present form he should be very glad if it proved of service to those interested either in the printing industry or in the manufacture of printing machinery.

The President conveyed the thanks of the Institution to Mr. Powrie for the labour he had bestowed upon the paper, which gave so excellent a detailed description of the mechanism of several of the principal kinds of typographic printing machinery.

Mr. Cecil Clay wrote that he thought there were many points upon which practical printers might derive great advantage from the wider experience of mechanical engineers. For instance, the two-revolution machines, described in page 112, in their improved and accepted forms are to all intents and purposes an American importation, and are being largely adopted by English printers. No doubt practical printers are able to form a fairly sound judgment as to the merits of these and other machines, in respect of their actual printing capabilities, that is, their capability to print true and to give an efficient ink-distribution, and their rigidity to withstand the constant and the varying pressures to which they are subjected. But a further consideration of great importance to the user is durability, inasmuch as the price of this American machinery is practically double that of machines of the same size of the ordinary English pattern. It is on this point that information is required by printers, and in the writer's opinion it is to be sought from mechanical engineers rather than from practical printers themselves. From a mechanical point of view the ultimate decision respecting a two-revolution press lies in the method adopted for driving the bed of the machine. There are at least three more or less distinct movements in use at the present time for accomplishing this object, and innovations are always in prospect. The three may be readily identified under the following descriptions:—first, the upright-spindle motion; second, the mangle motion; third, the motions of the

(Mr. Cecil Clay.)

Century and Miehle printing machines, which are two modifications of the mangle motion, dispensing with the universal joint. Presumably all three cannot be perfect alike, or there would seem to be no necessity for more than one of them; and it should surely not be outside the range of mechanical engineering to pronounce which one is mechanically better than the other two. Although the printer may be quite satisfied that every one of the American machines offered to him is ideally perfect, so far as printing is concerned, yet he may have serious doubts as to the perfection of its mechanism, and as to the durability of the latter. The problem is simply to drive the machine bed, weighing with its apparatus and type forme about 15 cwts., through a distance of five feet and back, some two thousand times in one hour. Of the three methods in use, which is the best from a mechanical point of view for performing its task smoothly, efficiently, and with least wear and tear?

The great difference between English and American printers' engineers appears to the writer to be that the latter seem to go into the details of printing, and to find out what it is that printers want, and then to make it for them. It can hardly, he thinks, be a question of price, in view of the fact that the increased price asked by American makers is immediately given, as soon as ever they produce the right machine. This applies not only to the printing machine itself, but also with equal force to all printers' machinery. Printers know what they want, but in most cases cannot experiment for themselves; they need the services of the printers' engineer to supply their requirements.

MEMOIRS.

Alexander Bertram was born at Salton, Haddingtonshire, on 9th November 1853. He served his apprenticeship from January 1869 to November 1874 in the fitting shop and drawing office of the Wigan Coal and Iron Co., and during that time studied also in the engineering classes of the Wigan Mining and Mechanical School. He remained in the drawing office till February 1877, when he superintended the erection of pumping and hauling machinery at their Ladies Lane Colliery, Hindley. From October 1877 to the end of 1878 he was employed as foreman over outside fitters; and on 1st January 1879 was appointed superintendent of machinery under the Mines Regulation Act, for a large section of the company's collieries. At the end of 1879 he became mechanical engineer to the company, having charge of all the machinery connected with their collieries producing two million tons of coal per annum, and with an extensive steelworks and a range of ten blast-furnaces. In order absolutely to prevent overwinding at the collieries, and also to prevent winding engines from being started in the wrong direction, he invented and applied successfully an arrangement known as the "visor," which has been adopted at many other collieries both in this country and abroad. In 1896 he was appointed mechanical engineer to Messrs. Newton, Chambers, and Co., Thorncliffe Iron Works and Collieries, near Sheffield. His death, due to a short severe attack of pneumonia, took place on 10th January 1899, at the age of forty-five. He became a Member of this Institution in 1890.

Thomas Graham Elliott was born at Stockton-on-Tees on 30th March 1847. At an early age his father took him to Manchester, where he was educated at Mr. Ibbotson's academy, and afterwards received his engineering training in his father's works, Ardwick. In 1866 he went as draughtsman to Messrs. Beyer

Peacock, and Co., Gorton Foundry, and to other works. In 1871 he became head draughtsman to Messrs. Sharp, Stewart, and Co., Atlas Works, Manchester; then for a short time to Messrs. Tangye Brothers, Birmingham; and in 1876 to Messrs. Fairbairn, Naylor, Macpherson, and Co., Wellington Foundry, Leeds. Here two years later he was made manager of the tool department, and continued in this position up to his death, which took place from apoplexy on 17th April 1899 at the age of fifty-two. He invented a self-acting screwing machine, and was engaged in the design and construction of machine-tools of all kinds, especially for the manufacture of armour plates and guns. He became a Member of this Institution in 1882.

Sir JOHN FOWLER, Bart., K.C.M.G., was born on 15th July 1817, at Wadsley Hall, Sheffield. After receiving a good general education, at the age of seventeen he became a pupil of Mr. John Towlerton Leather of Leeds. On leaving his office he was employed for two years by Mr. J. U. Rastrick on the London and Brighton Railway. He then returned to Mr. Leather, for whom he acted as resident engineer on the Stockton and Hartlepool Railway. On its completion he remained two years as engineer and general manager and locomotive superintendent of this and of the Clarence Railway. In 1843 at the age of twenty-six he began work on his own account, and on behalf of Sir John Macneill inspected certain railways near Glasgow, and gave evidence about them before parliamentary committees. In the same year he became the chief engineer of the Sheffield and Lincolnshire, and several other railways projected from Sheffield; these he conducted through parliament, and directed their construction. Subsequently some of the chief works which he carried out, or about which he was consulted, were:—the Oxford Worcester and Wolverhampton, Severn Valley, and London Tilbury and Southend Railways; Liverpool Central Station; Northern and Western Railway of Ireland; lines in New South Wales and India; water works for Sheffield and Glasgow; Metropolitan Inner Circle, St. John's Wood, Hammersmith, Highgate and Midland, Victoria Bridge and Pimlico, and Glasgow Union and City Railways;

Millwall Docks; Channel Ferry. Of these probably the most novel and the most notable were the Metropolitan Railways and their connections, for which the first act was obtained in 1853, though the works were not commenced till 1860. In 1870, as one of a commission sent to Norway to examine the light railways there in use, with a view to their adoption in India, he reported in favour of 3 feet 6 inches for the Indian gauge, in preference to 2 feet 9 inches recommended by the other commissioners. In 1868, visiting Egypt for his health, he was employed by Ismail Pacha to design irrigation works, to plan a water-way across the Isthmus in competition with the Suez Canal, and to survey a railway to Khartoum. When the British government took control of the country, he placed all his information and experience of Egypt at their disposal; and for this service he was rewarded by being made in 1885 a Knight Commander of St. Michael and St. George. From 1881, in conjunction with his partner Mr. Benjamin Baker, he was occupied with the design and construction of the Forth Bridge; on the completion of which in 1890 a baronetcy was conferred upon him, and Mr. Baker was made a Knight Commander of St. Michael and St. George. Having been elected a Member of the Institution of Civil Engineers in 1844, he became a Member of Council in 1849, a Vice-President in 1859, and President for the two years 1866 and 1867. In his presidential address he sketched a scheme for engineering education, showing a high appreciation of the value of technical training for engineers. He became a Member of the Institution of Mechanical Engineers in 1847, the year of its establishment. His death took place at Bournemouth on 20th November 1898, at the age of eighty-one.

Sir DOUGLAS STRUTT GALTON, K.C.B., was born on 2nd July 1822, at Hadzor House, Droitwich, being the second son of Mr. John Howard Galton; his mother was the daughter of Mr. Joseph Strutt, of Derby, by whom the Derby Arboretum was presented to his townsmen. He first went to a school in Birmingham, and then spent three years in the house of a Swiss pastor near Geneva, where he acquired a knowledge of the French language. He was afterwards educated at Rugby School (Proceedings 1898, page 204); and at the

age of fifteen entered the Royal Military Academy at Woolwich, having chosen the army as a profession. Here he achieved the distinction of taking the highest place in every subject that was included in the final examination. Receiving his commission in the Royal Engineers in December 1840, he was at once employed under Sir Charles W. Pasley in the destruction of the "Royal George," which had sunk at Spithead in 1782 with such disastrous loss of life, and had ever since proved an obstruction to the navigation of the Solent. The first attempt to blow up the wreck had been made on 29th August 1839, the fifty-seventh anniversary of the vessel's sinking; but it was not until the end of 1840 that it was finally destroyed, by means of explosives fired for the first time by a voltaic battery. From 1843 he served for two or three years in connection with the fortifications at Gibraltar and Malta; and on returning to England in 1846 was engaged for a short time in the Ordnance Survey Office at Southampton. Being appointed upon the Railway Commission in 1847, he became associated with the Board of Trade, where he was first in charge of the statistical department. The breaking down of the railway bridge over the river Dee at Chester led to the appointment of a royal commission to investigate the application of iron to railway structures; he was then Lieutenant Galton, and was appointed secretary to the commission, and conducted the various experiments for them. At the Birmingham meeting of the British Association in 1849 (Report, page xxvii) he assisted Professor Willis in an experimental demonstration of the result arrived at by the investigation. In 1853 he took his commission as captain in the Royal Engineers; and in 1854 he was appointed an inspector of railways. In 1856 he became secretary to the railway department of the Board of Trade, and in this capacity visited the United States officially in the same year, and drew up a report upon American railways. From the experience so acquired he contributed to the Institution of Civil Engineers a paper on railway accidents, showing the bearing which existing legislation had upon them (Proceedings Inst. C.E., 1862, vol. 21, page 363); he pointed out that the deaths due to railway disasters were not abnormal, and deprecated the acquisition of

railways by the state, as well as undue legislative control. Important improvements which he also urged in the organisation of railway management resulted in advantages of which the value is now fully realised. In 1857, as one of the referees for the main drainage of London, he urged that Barking and Crossness were too near to the metropolis to be suitable sites for outlets into the river; and suggested that the sewage should be taken by means of a tidal channel to Sea Reach, some twenty or twenty-two miles further down the river, whereby a large amount of pumping would be avoided, and the sewage would be diluted on its way down the channel, and would be finally discharged into a large volume of water where it would be innocuous. Subsequent experience has fully confirmed his view that the volume of tidal water at the two higher points in the Thames is too small for thorough dilution of the sewage. When the first submarine telegraph cable laid across the Atlantic in 1857 had failed, and the failure had also occurred of the cable laid in 1859 in the Red Sea as part of a line to India, he was made chairman of the committee of investigation appointed by the government in 1859; the report drawn up by him and published in 1861 formed a valuable guide in all matters of submarine telegraphy; and later he was appointed a member of the consultative committee charged with advising upon all points concerning the laying of the 1865 cable from England to America. Having been a member of Sir Robert Rawlinson's commission formed in 1858, which had reported so unfavourably upon the state of barracks at home and in the Mediterranean station, he was appointed in 1860 Assistant Inspector General of Fortifications, and was entrusted by Lord Herbert with the design and construction of the Herbert Hospital at Woolwich, at that time the largest military hospital in the world, having as many as 650 beds; here he carried into practice his views regarding sanitation, alike for dwelling houses and for barracks. These views he published in three works entitled "Hospital Construction," "Healthy Dwellings," and "Healthy Hospitals." From 1862 to 1870 he was Assistant Under Secretary of State for War; and in 1870 was appointed Director of Public Works and Buildings, at what was then H.M. Board of Works; from the latter post he

retired in 1875. In 1866 he was appointed a member of a Royal Commission to enquire into the charges made for conveyance on the several railways of Great Britain and Ireland, and to ascertain whether it would be practicable to effect any considerable reduction in the charges, with a due regard to safety, punctuality, and expedition. Their principal report, which he joined in signing, was presented in 1867, and contained numerous recommendations since carried into effect; it also confirmed the opinion he had previously expressed in 1862 as to the inexpediency of the state purchasing or constructing railways. In 1876 he made a second visit to the United States, as one of the judges on this occasion at the Philadelphia Exhibition; and on his return he communicated to the Institution of Civil Engineers (Proceedings 1878, vol. 53, page 28) notes on railway appliances at the exhibition. In 1878 he entered upon that historical series of experiments on the effect of brakes upon railway trains, which have perpetuated his name in the annals of engineering. These experiments were made with the assistance of Mr. Westinghouse on the London Brighton and South Coast Railway, the North Eastern Railway, and the Paris Lyons and Mediterranean Railway; and the results were fully reported and discussed by himself in three papers which he contributed to this Institution (Proceedings 1878, pages 467 and 590; and 1879, page 170); by these were elucidated for the first time the laws of friction in relation to railway brakes. In 1871 he became general secretary of the British Association, and retained the post for twenty-four years, until elected President for 1895–6. In his presidential address at the Ipswich meeting in 1895 (pages 31–4) he strongly urged that the government should establish a National Physical Laboratory, on the principle of the Reichs-Anstalt at Charlottenburg near Berlin. In order to make himself fully acquainted with every detail of that great institution, he paid two visits to Berlin, and prepared a report to present to the British Association. Later he summed up his conclusions in the evidence he gave before the royal commission, which was appointed by the government to report upon the scheme suggested in his address at Ipswich in 1895. The last occasion of his attending a meeting at the Royal Society was in order

to take his place upon the committee appointed to consider the preliminary steps in connection with the grant promised by the government for the purpose of a National Physical Laboratory. He was made a Companion of the Bath in 1865 when at the War Office, and a Knight Commander of the same order in the Queen's jubilee year 1887. He was made a Commander of the Legion of Honour in 1889, and afterwards a Knight of Grace of the order of St. John of Jerusalem in England; and he held the orders of the Crown of Prussia and of the Medjidie of Egypt. He was elected a Fellow of the Royal Society in 1863, and was also a Member of the Council; and he received the honorary degrees of D.C.L. from Oxford, and of LL.D. from Durham and Montreal. Having been an Associate of the Institution of Civil Engineers from 1850, he was elected an Honorary Member in 1894. He became a Member of this Institution in 1862, and was a Member of Council from 1888, and a Vice-President from 1892. In the arrangements for the new House of the Institution he took an active part throughout, attending numerous committee meetings, and advising upon the many details coming up for decision; and he was present for the last time at the opening meeting in the new building on 9th February 1899. In 1876 he joined in founding the Sanitary Institute, of which he was a Vice-President from its incorporation in 1888; and his last public appearance was as chairman at a meeting of the Institute on 13th February. The subject under consideration was the water supply of London; and he expressed the opinion that it would be prudent for London to be content with the Thames area, and as far as possible to improve the water obtained from this area by storing it and by removing the sources of pollution which exist in the upper valley of the Thames and in the valley of the Lea. On this occasion he spoke of himself as now experiencing the effects of advancing years, and he appeared to be slightly indisposed. Some days later, blood poisoning set in, which resulted in his death on 10th March 1899 in the seventy-seventh year of his age. He was a justice of the peace for Worcestershire, and also a county councillor. The interment took place at Hadzor Church, adjoining his birthplace. A memorial

service was held in St. Peter's Church, Eaton Square, London, at which an address was delivered by the Dean of Gloucester, Dr. H. Donald M. Spence, appreciating from personal knowledge the practical importance of his life's work to the health, happiness, and welfare of his fellow-countrymen, and of mankind at large.

JEREMIAH HEAD was born at Ipswich on 11th July 1835. After receiving his early education at home, in a private school at Ipswich, and at Tulketh Hall near Preston, at the age of sixteen he was articled in 1852 for five years in the works of Messrs. Robert Stephenson and Co., Newcastle-on-Tyne, where he served three years and a half in the pattern-making, fitting, and erecting shops, and the remaining year and a half in the drawing office. During the latter part of his time and for a year subsequently he was engaged in the designing and erection of two compound mill engines; one of these, for Messrs. Henry Pease and Co.'s Priestgate Woollen Mills at Darlington, was fitted for the first time with a true parabolic governor in 1856, to which he subsequently added an air cataract to prevent hunting; the other engine, for Messrs. Annandale and Sons' Paper Mills at Shotley Bridge, was also fitted with a similar governor, of which there were several later examples in Messrs. R. Stephenson and Co.'s works. A simplified arrangement with crossed arms, forming a closely approximate parabolic governor, was subsequently devised by him for a large single-cylinder horizontal engine driving two plate-mills at the Newport Rolling Mills, Middlesbrough; and nine others were also employed at the same works. Of these governors and of their successful working he gave a description to the first Middlesbrough Meeting of the Institution (Proceedings 1871, pages 213–23), for which he acted as honorary local secretary. For two years 1857–9 he was employed under Mr. Robert Stephenson and Mr. G. H. Phipps in the reconstruction of Rowland Burdon's celebrated cast-iron bridge, originally erected in 1796 over the river Wear for connecting Sunderland and Monkwearmouth; it consisted of a single arch, forming an arc of a circle of 237 feet span and 33 feet rise, with a clear height of 99 feet above low water (Proceedings 1858, page 261). The Royal Agricultural Society

having offered a prize for a steam plough, he was entrusted with the work of developing into practical form the idea conceived by Mr. John Fowler of Leeds; with the result that the prize was won at the Chester Show in 1858 by the plough made under his direction at Messrs. Stephenson's works, whence fifteen more of the same kind were afterwards turned out. Subsequently he went for a short time to Messrs. Kitson and Co., Airedale Foundry, Leeds; and then became manager of the Steam Plough Works of Messrs. John Fowler and Co. in Leeds until 1860; and besides constructing nearly a score of steam ploughs, he devised a plan of signalling by lamps to facilitate steam-ploughing at night. As agent for the firm he next spent some time at Swindon, demonstrating the practical capabilities of the steam-ploughing tackle upon farms in Wiltshire. In the spring of 1863 he joined Mr. Theodore Fox in founding the firm of Fox, Head, and Co., and erected the Newport Rolling Mills, Middlesbrough, for the manufacture of iron plates. Here they employed 600 men, and produced 400 tons of finished iron per week, using machinery which dealt with larger masses of wrought-iron than had hitherto been worked. For over twenty years he devoted himself to the details of this business, and carried into practice a plan of profit-sharing with his workmen, which was so far successful that no labour disputes arose between them even during a disturbed period. In other ways also he sought to improve the condition of the workmen; and largely owing to his initiation Middlesbrough was the first town in England to apply for the establishment of a school board after the passing of the act. Of this board he was for several years an active member. With the object of improving the industries of the district and increasing its prosperity, he originated in 1864 the Cleveland Institution of Engineers, whose interests he served for three years as honorary secretary, and afterwards for three years as President, performing during the whole of the time much work of great benefit to the district. In 1885 the firm of Messrs. Fox, Head, and Co. was dissolved, and he devoted his time and energy to wider interests as a consulting engineer in Cleveland. In 1888 he laid out the Bowesfield Iron Works at Stockton-on-Tees, and in 1891 the New British Iron Works at Corngreaves near Birmingham. In

January 1894 he moved his offices from Middlesbrough to Westminster, where he thenceforth practised. Several times he visited iron works in Norway; and in Spain he examined manganese mines near Santander, coal mines near Oviedo, and iron ore deposits near Bilbao and Santander. To the United States he made ten visits, bringing back thence many valuable suggestions for practical improvements in engineering industries in this country. The results of his observations he freely communicated to the leading professional societies, in papers on the iron ore deposits in Scandinavia, on American and English steel manufacture, and other subjects; his latest contribution was a paper prepared in conjunction with his son upon the Lake Superior iron ore mines, which was presented to the Institution of Civil Engineers on 14th February 1899. He acted as consulting engineer in this country for the Otis Steel Works in Ohio, and for the Alberta Irrigation in Western Canada. In 1894 he visited Salt Lake City, and reported upon a Mormon railroad; and also upon a proposed railroad from the iron works in Alabama to the Tennessee River. As an arbitrator he settled many questions between employers and workmen, including differences at Messrs. Bolckow Vaughan and Co.'s Works and at the Barrow Steel Works. In 1896 he reported for the Indian government upon the iron ore deposits at Salem in the Madras presidency, arriving at the conclusion that it would be impracticable to smelt the ores on the spot in the absence of suitable fuel and in the face of the competition of English iron delivered there. He became a Member of this Institution in 1859, and again after an interval in 1869; a Member of Council in 1874; and a Vice-President in 1880. At a season of sudden emergency, with characteristic self-forgetful readiness, he complied with the unexpected request of the Council to accept the presidency; and by the admirable manner in which he bore the anxieties and fulfilled all the duties of President during the two years 1885–6, he greatly enhanced the dignity and stability of the Institution, and won the warmest esteem of the Members. In 1893 he obligingly took upon himself as a Past-President the organization of the arrangements for the second Summer Meeting in Middlesbrough, for which he personally procured and arranged the extensive statistics

furnished to the Members in the descriptions of the numerous works they then visited. On that occasion also, as well as in his two Presidential addresses, he enriched the Institution Proceedings with a store of information, interspersed with suggestions affording material for reflection. The paper he then read, on recent developments in the Cleveland iron and steel industries (Proceedings 1893, page 224), gave the best description that has yet been written of that remarkable district. He was a Member of the Institution of Civil Engineers from 1875; and of the Iron and Steel Institute from 1869, the year of its formation. In 1893 he was President of the mechanical section of the British Association at the Nottingham meeting. From 1894 he was a Member of Council of the Federated Institution of Mining Engineers. Having considerably overtaxed his strength, he went at the beginning of the present year to Bournemouth for a short rest, and afterwards to Hastings, where he appeared to be progressing favourably towards speedy re-establishment of health, when his death occurred suddenly from congestion of the brain on 10th March 1899 at the age of sixty-three.

Peter Rothwell Jackson was born in Liverpool on 22nd July 1813; but shortly afterwards his parents went to live in Bolton, where he commenced work at an early age, serving his apprenticeship as an engineer with the firm of Rothwell, Hick, and Rothwell, at the Union Foundry, which was then one of the largest foundries in Lancashire, affording employment to about 400 men. During his apprenticeship he made a foot lathe, to which amongst other devices he fitted two cylindrical brushes for cleaning boots, this being probably the earliest attempt at shoe-cleaning by machinery. He also invented an improved method of cutting screw-threads of various pitches on steel taps and other short screws, at that time a somewhat difficult operation. Later he took out a patent, the first after Bramah's, for improvements in hydraulic presses, his attention having been drawn to this subject by the frequent bursting of the press cylinders at the Union Foundry; although the thickness of metal in them had been increased to as much as 8 inches, they frequently gave way. He therefore adopted the bold expedient of

reducing the cylinder walls from 8 inches to only 7-8ths inch thickness, extending the main tension-bolts of the press so as to permit of the cylinder being supported from below, and securing the necessary circumferential strength by hooping the cylinder with three sets of wrought-iron hoops carefully shrunk on, after the manner subsequently adopted by Sir William Armstrong in the manufacture of heavy ordnance. He was indeed anxious to apply this method to gun-making, but was dissuaded from doing so by his friend, Mr. John George Bodmer, who, while entirely approving of the plan, represented the difficulties he had himself experienced in trying to introduce novel ideas to government officials. The press cylinders thus strengthened proved highly successful; and the hydraulic presses as made by him continued in use until cast-steel hydraulic cylinders could be obtained at a reasonable cost. In consequence of a dissolution of partnership in the firm, the works management at the Union Foundry devolved chiefly on himself when only about nineteen years of age and still in his apprenticeship. Although this position carried with it far too much responsibility for his years, it no doubt developed his capabilities, and proved most useful to him in after life. When about twenty-two years old he left Messrs. Rothwells, and with his two brothers purchased the Wharf Foundry in Bolton. Being a sound mechanic and a most patient designer, he spared no pains to give the best possible form to any machine he had in hand, whether the main idea had originated with himself or with another. The ultimate success of Mr. Bodmer's plan for rolling railway-wheel tires was chiefly owing to the thought and pains Mr. Jackson bestowed upon working it out practically; he constructed the mill in such a way that it rolled the tires so exactly as to enable many of them to be shrunk on their wheels and put to work without either boring or turning. Even now the Jackson tire-mill is considered by competent judges to be capable of turning out better work than any other. The same thought and care characterised the working out in all their details and accessories of his own inventions, in 1848 and 1854 respectively, of a hydraulic starting apparatus and of a wheel-moulding machine for toothed gearing. Of the former he gave a description to this Institution in 1848 (Proceedings

April, page 12), when he had had it at work for two or three months. The moulding of toothed wheels by machinery has since become practically universal; and so perfectly were all the conditions met by his method that several of his earlier machines are still in successful operation, notwithstanding the adverse conditions under which they work, owing to the dust and sand inseparable from an iron foundry. The first of these moulding machines he described to the Institution in 1855 (Proceedings, page 41), with particulars of the work it had done during the eight or nine months it had been in operation since starting. Both the rolling of the tires and the making of the hydraulic starting apparatus and of the toothed wheels were carried out by him at the Salford Rolling Mills, Manchester, established by him in 1840 for the manufacture of railway tires, and subsequently developed into a large iron and steel foundry, and in recent years into electrical engineering works. He was one of the original Members of this Institution from its formation in 1847; and he used often to recall with interest the fact that he had attended the first meeting, held in Birmingham on Wednesday 27th January 1847, under the presidency of George Stephenson, at which the Institution was established (Proceedings 1897, pages 259–260). His death took place at his residence, Blackbrooke, Skenfrith, Monmouthshire, on 8th February 1899, in the eighty-sixth year of his age.

William Laird was born at Birkenhead on 11th April 1831, being the eldest son of Mr. John Laird, M.P. After receiving his education in Liverpool and at Harrow, he was taken into his father's office in the iron shipbuilding works of Messrs. William Laird and Son. Devoting himself to mastering the details of scientific shipbuilding, he early became the head of the drawing department, where he had the complete control of the work of designing, and the revision of all contracts for work undertaken by the firm. When this department was taken over by his younger brother Henry Hyndman (Proceedings 1893, page 205), he still devoted much time to it himself. On 1st January 1860 he was admitted a member of the firm, along with his brother John, and the title was changed to

John Laird, Sons, and Co. At the end of 1861 his father retired from the firm, and in the middle of 1862 Mr. Henry Hyndman Laird was admitted into what then became the firm of Messrs. Laird Brothers, of which Mr. William Laird was the senior partner. Among the famous productions of the works under his guidance were the ironclad battle-ship "Agincourt" in 1865, followed by the "Vanguard," the "Britannia," and many other vessels; then in 1880 three channel steamers for the London and North Western Railway; in 1886 the "Rattle-snake" torpedo gunboat, the first of a long line of high-speed boats; in 1889 the "Columbia," the largest merchantman ever constructed on the Mersey, owned by the Hamburg American Company; and recently the first-class battle-ships "Royal Oak" and "Mars," and a fleet of 30-knot torpedo destroyers, as well as one boat of 33 knots; also the "Cephalonia," the "Westernland," and the "Noordland"; the battle-ship "Glory," of 12,500 tons, at present in the building dock; and Mr. Vanderbilt's floating palace "Valiant." For the Irish mail service between Kingstown and Holyhead the steamers "Ulster," "Munster," and "Connaught," were built in 1860, of which he was the actual designer; then in 1885 the royal mail steamer "Ireland," probably the fastest paddle-boat in the world; and in 1896 four twin-screw steamers, "Ulster," "Leinster," "Munster," and "Connaught," having a speed of nearly 24 knots, for the accelerated Irish mail service, to replace the three built in 1860. Since the death of Mr. John Laird on 25th January 1898, the whole burden of the firm was principally borne by Mr. William Laird, who continued to attend to business up to a few days before his death, which occurred on 7th February 1899, in the sixty-eighth year of his age. He became a Member of this Institution in 1872, and was a Member of Council from 1887. He was also a Member of the Institution of Naval Architects, and a Member of their Council. From the incorporation of Birkenhead in 1877 he had a seat on the Town Council; and was Mayor for the three years 1880–1–2, and again for 1886. In 1875 he was appointed a justice of the peace for the county of Cheshire; and when the borough bench was formed in 1878, he became one of the first magistrates of Birkenhead.

John William Naylor was born on 1st August 1827, at Folly, Beeston Hill, Leeds, where his family were well known as cloth manufacturers. In 1843 he went to work in the old Wellington Foundry of Sir Peter Fairbairn, maker of flax and woollen machinery. In 1863, two years after the death of Sir Peter Fairbairn, he was taken into partnership by his son Sir Andrew Fairbairn, along with Mr. T. S. Kennedy (Proceedings 1894, page 598); and from 1883 he was managing director of the concern. He was also a director of the Lancashire and Yorkshire Railway, chairman of the income-tax commissioners in the Leeds district, and a justice of the peace for Leeds and for the West Riding of Yorkshire. He resided at Chapel Allerton, near Leeds; and his death took place suddenly while on a visit to London, on 4th June 1899, in the seventy-second year of his age. He became a Member of this Institution in 1861, and was also a Member of the Iron and Steel Institute.

Exham Phillips was born in Cork in 1847. After receiving his early education there, he served an apprenticeship from 1859 to 1866 in the engineering works of Messrs. Richard Perrott and Sons, Cork. He then matriculated in the department of engineering at the Queen's College, Cork, of the Royal Irish University, and studied in the course from 1867 to 1869. From 1869 to 1885 he was manager of the Neville Iron Works of Messrs. Walker and Emly, Newcastle-on-Tyne. In 1886 he became manager of the drawing office of Messrs. Thomas Bradford and Co., Crescent Iron Works, Salford, Manchester. His death occurred on 27th March 1899 in the fifty-second year of his age. He became an Associate Member of this Institution in 1895.

William Robertson was born at Newfaulds in the parish of Lochwinnoch, Renfrewshire, on 23rd February 1833, his father being a farmer. After being educated at the parish grammar school, he served an apprenticeship for five years 1852–57 in the Eglinton Engine Works of Messrs. A. and W. Smith in Glasgow; and then worked as a journeyman in 1858 and 1859 with Messrs. Caird and Co.,

engineers and shipbuilders, Greenock. At the end of 1859 he went under an engagement to Sochia near Smyrna in Asia Minor, to erect sugar machinery. In 1863 he went to Shanghai, China, and was engaged as chief engineer in steamers running on the coasts of China and Japan. In 1867 he became a partner in the firm of Messrs. Boyd and Co., engineers and shipbuilders at Shanghai; and was principal in starting works for the firm in Nagasaki and Yokohama, Japan, on behalf of the Japanese government. In 1892 he returned to England, and resided principally at Hampstead, London, where his death took place on 8th November 1898 in the sixty-sixth year of his age. He became a Member of this Institution in 1879.

Frederick Ryland was born in Birmingham on 28th March 1845, being the eldest son of Mr. William Ryland, who for many years was manager of Messrs. Elkington and Co.'s electro-plating works. On leaving school he was apprenticed in 1861 to the engineering firm of Messrs. May and Mountain, Suffolk Works, Birmingham; from whom in 1866 he went as engineering assistant to the works of Messrs. Archibald Kenrick and Sons, hardware manufacturers, Spon Lane, West Bromwich. In 1883, when this business was formed into a company, he became a director. He was a magistrate of West Bromwich, and took an active interest in the welfare of the educational and charitable institutions of the town. His death took place on 11th February 1899 at the age of fifty-three, after four months' illness resulting from an attack of influenza. He became a Graduate of this Institution in 1866, and a Member in 1869.

Elliott & Fry.

W. H. White
March 1899

The Institution of Mechanical Engineers.

PROCEEDINGS.

April 1899.

The Spring Meeting was held in the House of the Institution, St. James's Park, London, on Thursday, 27th April 1899, at Half-past Seven o'clock p.m.; Sir William H. White, K.C.B., LL.D., D.Sc., F.R.S., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that H.R.H. the Duke of York had accepted the invitation of the Council to become an Honorary Member of the Institution.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and the following one hundred and four candidates were found to be duly elected:—

MEMBERS.

Appleby, George William,	Hong Kong.
Atherton, Thomas,	Warrington.
Awdry, Walter Llewellyn,	Birmingham.
Bayley, George Ridley,	Liverpool.
Beaumont, Roberts,	Leeds.
Byrne, John Joseph,	Athy.
Clark, Henry,	Stockton-on-Tees.

Craven, John Alfred, ...	Sheffield.
Dan, Takuma, ...	Tokyo.
Deas, James, ...	Warrington.
Drew, Alexander, ...	Edinburgh.
Drummond, Walter, ...	Glasgow.
Durston, Sir Albert John, K.C.B., R.N.,	London.
Elford, Ernest John, ...	Portland.
Ford, Thomas Wharton, . . .	London.
Ford-Moore, Arthur Pilcher, . .	London.
Fraser, Patrick, ...	Arbroath.
Hammond, Robert, ...	London.
Holmes, John Henry, ...	Newcastle-on-Tyne.
Hosgood, Octavious Sidney, . . .	Cardiff.
Hughes, George, ...	Manchester.
Hunter, George Lewis, . . .	Cardiff.
James, Herbert Holland, . . .	London.
Kekewich, George Ormond, . . .	London.
Kilgour, Martin Hamilton, . . .	Cheltenham.
King, John James, ...	Nottingham.
Kirkaldy, William George, . . .	London.
MacDonald, John, ...	Glasgow.
Mastrantonis, Panayotis, . . .	Piraeus.
Nisbet, William Holmes, . . .	Brisbane.
Osborne, Thomas Peter, . . .	Derby.
Parker, Thomas Hugh, . . .	Wolverhampton.
Peet, James, ...	Trinidad.
Quin, Robert Cornelius, . . .	Blackpool.
Ride, Samuel, ...	Manchester.
Robins, George Mead, ...	Sutton, Surrey.
Sandeman, Edward, ...	Plymouth.
Shepherd, Richard Lillington, . .	Queenstown, Tasmania.
Smethurst, William, ...	Manchester.
Surtees, Henry Wardale, . . .	Derby.
Unsworth, Herbert George, . .	Swansea.
Urie, William Montgomerie, . .	Glasgow.
Waddington, Richard, . . .	London.

Williams, William Henry, . . .	Swindon.
Wilson, Charles Louis Napoleon, . .	Bilston.
Wilson, William Hope, . . .	Glasgow.
Yates, Joseph, ...	Manchester.
Yates, Walter, ...	Manchester.

ASSOCIATE MEMBERS.

Ambrose, Sewell Powis, . . .	Manchester.
Arnold, Arnold Attwood, . . .	Ipswich.
Baber, Samuel Ernest, . . .	Bristol.
Backhouse, John, ...	London.
Bateman, Arthur Henry, . . .	London.
Bettig, Robert, ...	Lille.
Beves, Norman Ellison, . . .	Edinburgh.
Cannell, William, ...	Coventry.
Chapman, Samuel, ...	Manchester.
Clarke, Arthur Laver, . . .	Maldon.
Dodridge, Frederick, ...	Devonport.
Dutch, Ernest, ...	Wigan.
Fairley, Frank, ...	London.
Flint, Leonard Robert, . . .	London.
Fox, Henry Shoolbred, . . .	London.
Fulcher, George Chambers, . . .	London.
Gibbins, John Ernest, ...	Sheffield.
Girvan, William, ...	Sandakan, B.N. Borneo.
Hadley, William Pearce Holbrow, .	Silchar.
Hepworth-Collins, Walter, . . .	Dublin.
Hollingsworth, Allen Alexander, .	Sheffield.
Holmes, Harry, ...	Birmingham.
Horsnaill, William Owen, . . .	Manchester.
Hunt, Henry, ...	London.
McFerran, Howard A., . . .	London.
Nettlefold, Godfrey, ...	Birmingham.
Oates, Arthur Job, ...	Darlaston.
Oswald, George Herbert, . . .	Newport, Mon.

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Petter, Percival Waddams, . . .	Yeovil.
Price, William Frederick, . . .	Liverpool.
Rapson, Josiah Trevor, . . .	London.
Richardson, John Robert, . . .	Lincoln.
Roberts, Basil Owen, ...	King's Lynn.
Rosevere, Gerald Rhodes, . . .	Birmingham.
Scott, Robert, ...	Klipdam, S. Africa.
Shawcross, George Nuttall, . .	Bolton.
Somerville, Frederick Herbert, . .	Chelmsford.
Tester, William Andrews, . . .	London.
Trunchion, William Thomas Fawdon, .	Bedford.
Walker, William Peto, . . .	London.
Wheeler, George Uzziah, . . .	Birmingham.
Whitehead, James Peter, . . .	Manchester.
Williams, Hal, ...	London.
Williamson, Edward, ...	London.

ASSOCIATE.

Dadge, Nelson, ...	Edinburgh.

GRADUATES.

Dawson, John Edward, . . .	Bradford.
Dodge, Samuel Brickhill, . . .	Hove.
Edwards, William Bernard, . .	Birmingham.
Goodman, Frank Adolphus, . . .	Torquay.
Marsden, Alfred, ...	Leyland, Lancs.
Mayo, William Henry, . . .	Malvern.
O'Brien, Henry Eoghan, . . .	Bolton.
Prosser, Robert Walter Ostell, . .	Blaydon-on-Tyne.
Sanderson, Herbert William, . .	Nottingham.
Taylor, Frank Coston, . . .	Bolton.
Wray, Romulus Paul, ...	London.

The President further announced that the following six Transferences had been made by the Council since the last General Meeting:—

ASSOCIATE MEMBERS TO MEMBERS.

Bradley, James William, . . .	Wolverhampton.
Dawson, Philip, ...	London.
Mansfield, Edwin Albert, . . .	London.
Richmond, William Frederick, . .	Longton, Staffs.
Roots, James D., ...	London.

GRADUATE TO ASSOCIATE MEMBER.

Jones, Arthur Dansey, . . .	Manchester.

The President said that at the previous meeting the Institution had been honoured with the presence for the last time of their late Vice-President, Sir Douglas Galton. Shortly after the meeting he had been taken seriously ill, and his death had occurred just seven weeks ago, to the great regret not only of this Institution but of many other societies also. The vacancy thereby occurring had been supplied by the Council, in conformity with the articles of association, by the appointment of Mr. Arthur Tannett Walker, of Leeds, as a Vice-President for the present year; and the vacancy consequently created on the Council had been filled by the appointment of Mr. Henry Lea, of Birmingham, as a Member of Council for the present year, his name being the next highest in the voting for the election at the Annual General Meeting. Agreeably with the articles of association, both these gentlemen would retire at the next Annual General Meeting, and would be eligible for re-election.

The President then delivered his Inaugural Address on "The Connection between Mechanical Engineering and Modern Shipbuilding."

The Meeting was then adjourned at ten minutes past Nine o'clock to the following evening. The attendance was 170 Members and 68 Visitors.

The Adjourned Meeting was held in the House of the Institution, St. James's Park, London, on Friday, 28th April 1899, at Half-past Seven o'clock p.m.; Sir William H. White, K.C.B., LL.D., D.Sc., F.R.S., President, in the chair.

The following Paper was read and discussed:—

"Evaporative Condensers"; by Mr. Harry G. V. Oldham, *Associate Member*, of London.

The Meeting then terminated at a Quarter before Ten o'clock. The attendance was 103 Members and 68 Visitors.

ANNUAL DINNER.

The Annual Dinner of the Institution was held at the Hotel Cecil, Strand, on Wednesday evening, 26th April 1899, and was largely attended by the Members and their friends, the company numbering upwards of three hundred. The President occupied the chair; and the following Guests accepted the invitations sent to them, although those to whom an asterisk * is prefixed were unavoidably prevented at the last from being present. The Right Hon. George J. Goschen, M.P., D.C.L., LL.D., F.R.S., First Lord of

the Admiralty; the Right Hon. the Earl of Hopetoun, G.C.M.G., P.C., Lord Chamberlain; the Right Hon. Rear-Admiral Lord Charles Beresford, C.B., M.P.; the Hon. J. C. Burns, President of the Chamber of Shipping; Sir Thomas Sutherland, G.C.M.G., M.P., LL.D., Chairman of the Peninsular and Oriental Steam Navigation Co.; Vice-Admiral Sir Frederick G. D. Bedford, K.C.B., Lord of the Admiralty; Lieut.-General Sir Henry Brackenbury, K.C.B., K.C.S.I., R.A., Director-General of Ordnance; the *Right Hon. Sir Francis H. Jeune, President of the Probate, Divorce, and Admiralty Division; the *Hon. Sir Walter G. F. Phillimore, Bart., Justice of the Queen's Bench Division; Rear-Admiral Arthur K. Wilson, C.B., V.C., Controller of the Navy; the Hon. Sir George Shenton, President of the Legislative Council of Western Australia; Sir William C. Roberts-Austen, K.C.B., D.C.L., F.R.S., Honorary Life Member; *Monsieur D. Dumont, President of the Société des Ingénieurs Civils de France; Sir Albert John Durston, K.C.B., Engineer-in-Chief of the Royal Navy; Major-General J. B. Sterling; *Mr. W. G. Ellison Macartney, M.P., Financial Secretary to the Admiralty; *Sir John Jackson, F.R.S.E.; Captain Fiéron, Naval Attaché to the French Embassy; Colonel Edmund Bainbridge, C.B., Chief Superintendent of the Ordnance Factories; Commander Kawashima, Naval Attaché to the Japanese Embassy; the *Worshipful the Mayor of Devonport, Alderman W. Hornbrook; *Mr. J. A. Travers, Prime Warden of the Fishmongers' Company; *Captain Wilmot H. Fawkes, R.N.; *Mr. T. H. Ismay, Chairman of the White Star Line of Steamships; Professor W. Cawthorne Unwin, F.R.S., Honorary Life Member; Professor W. F. M. Goss, Purdue University, Lafayette, Indiana, U.S.A.; Professor D. E. Hughes, F.R.S.; *Mr. Edwin Tate; Mr. Quintin Hogg, The Polytechnic.

Mr. W. H. Preece, C.B., F.R.S., President of the Institution of Civil Engineers; Mr. Edward P. Martin, President of the Iron and Steel Institute; Mr. Joseph W. Swan, F.R.S., President of the Institution of Electrical Engineers; *Mr. William Armstrong, President of the North of England Institute of Mining and Mechanical Engineers; Mr. Charles D. Abel, President of the Chartered Institute of Patent Agents; *Dr. John Inglis, President of

the Institute of Marine Engineers; Dr. J. H. T. Tudsbery, Secretary of the Institution of Civil Engineers.

Mr. Alfred Bache; Mr. James S. Beale, Honorary Solicitor; *Mr. William Gowland; *Mr. Harry Lee Millar, Honorary Treasurer; Mr. Harry G. V. Oldham; *Mr. William Powrie; Mr. Basil Slade, Architect; Mr. C. J. Wilson, F.I.C.

The President was supported by the following officers of the Institution:—*Past-Presidents*, Sir Lowthian Bell, Bart., F.R.S.; Sir Edward H. Carbutt, Bart.; Mr. Samuel W. Johnson; Mr. E. Windsor Richards; and Mr. Percy G. B. Westmacott. *Vice-Presidents*, Mr. Arthur Keen; Mr. Edward P. Martin; Mr. T. Hurry Riches; and Mr. A. Tannett Walker. *Members of Council*, Mr. John A. F. Aspinall; Mr. Henry Chapman; Mr. Henry Davey; Mr. Bryan Donkin; Mr. H. Graham Harris; Mr. Henry Lea; Mr. J. G. Mair-Rumley; and the Right Hon. W. J. Pirrie.

After proposing the usual loyal toasts, the President announced that H.R.H. the Duke of York had accepted the nomination of the Council as an Honorary Member of the Institution. Sir Edward H. Carbutt, Bart., Past-President, proposed the toast of "The Navy, Army, and Reserve Forces," which was acknowledged by the Right Hon. George J. Goschen, M.P., D.C.L., LL.D., F.R.S., First Lord of the Admiralty, who, in responding for the Navy, dwelt upon the close connection of mechanical engineers with naval architecture and marine engineering. They were invisible contributors to many of the triumphs of civil engineers and naval architects; and any one descending into the interior of a warship would see at a glance to how vast an extent mechanical engineers had contributed to the construction of the whole. Such a vessel might indeed appropriately be called a museum of mechanical engineering. Air, fire, water, and electricity had been subdued by mechanical engineers for the accomplishment of their work; and they were still ousting from their present domain of activity other forces besides human labour. But human activity they could not entirely succeed in superseding in a man-of-war, where trained intelligence was now more than ever required to put their appliances into efficient operation. Such training schools as the "Vernon" and the "Defiance" were sending

forth naval officers who, he might venture to say, were themselves to a certain extent mechanical engineers. The education of naval officers had now been in a great degree modified through the Institutions of Mechanical Engineers, Naval Architects, and Electrical Engineers. The whole navy had thereby been raised intellectually, and had become habituated to higher, or at any rate more complicated, duties than those which in former days had to be performed. Though some might have their misgivings whether in the stress of storm or the heat of battle the mechanical complications of a warship could be correctly manipulated, he was satisfied that the coolness of the present naval officers could be confidently relied upon, because of their practical knowledge of the mechanism, and their readiness of resource if any part of it should get out of order. In the future advances effected by mechanical engineers he trusted there would be simplicity as well as complexity, because he feared lest in a man-of-war greater complexity might hardly be compatible with the efficient performance of the duties to be discharged. Lieut.-General Sir Henry Brackenbury, K.C.B., K.C.S.I., R.A., Director-General of Ordnance, replied for the Army and Reserve Forces. The toast of "Our Guests," proposed by the President, was acknowledged by Sir Thomas Sutherland, G.C.M.G., M.P., LL.D., Chairman of the Peninsular and Oriental Steam Navigation Co.; by the Hon. Sir George Shenton, President of the Legislative Council of Western Australia; and by Professor W. F. M. Goss, of Purdue University, Lafayette, Indiana, U.S.A. Mr. E. Windsor Richards, Past-President, proposed the toast of "Kindred Societies," which was acknowledged by Mr. W. H. Preece, C.B., F.R.S., President of the Institution of Civil Engineers. The remaining toast of "The Institution of Mechanical Engineers" was proposed by the Right Hon. Rear-Admiral Lord Charles Beresford, C.B., M.P., who suggested that the position of engineers in the fleet should be officially enquired into; for his own part he should like to see both the Director of Naval Construction and the Engineer-in-Chief occupy the rank of Rear-Admiral. The toast was acknowledged by the President.

ADDRESS BY THE PRESIDENT,

Sir WILLIAM H. WHITE, K.C.B., LL.D., D.Sc., F.R.S.

THE CONNECTION BETWEEN MECHANICAL ENGINEERING AND MODERN SHIPBUILDING.

For the first time the Presidential Chair of this Institution is occupied by a Naval Architect. Marine engineering has been worthily represented by the late Mr. John Penn, who served as President for four years, 1858–59 and 1867–68. Mr. Robert Napier, distinguished both as a shipbuilder and an engineer, was elected President three years in succession, 1863–64–65. After an interval of thirty-three years you have conferred upon another representative of the shipbuilding industry the honour of serving the Institution as its President, at a notable period of its history. Entering its new and permanent home, the Institution must in many ways make new departures, if its highest efficiency and usefulness are to be realised. Those charged with the conduct of its affairs consequently have the greater responsibility. Speaking on behalf of the Council, I can assure you that no effort will be spared to advance the best interests of the Institution, and to provide for all classes of its members.

Mechanical engineering has intimate relations with all other branches of engineering. With none has it been more closely associated than with shipbuilding in recent times, and upon none has its influence been greater or more beneficial. The growth of our shipbuilding industry and the marvellous development of our mercantile marine during the last forty years are matters of common knowledge. The causes which have contributed to this supremacy are not so well understood, and the part which mechanical engineering has played is not generally appreciated. In this address my principal aim will be to indicate the directions in which shipbuilding and the working of ships have been influenced by mechanical engineering.

The total tonnage of steamships for the whole world is about 19,500,000 tons, and of sailing ships about 7,050,000 tons. The United Kingdom owns 54 per cent. of the total steamship tonnage, and 29 per cent. of the sailing ship tonnage. The British Empire owns 57 per cent. of the steamship tonnage, and over 35 per cent. of the sailing ship tonnage. Last year (1898) we launched more than a million tons of shipping which were registered in British ports as additions to our fleet.

British shipbuilding attained its highest production last year, when, according to the valuable returns issued by Lloyd's Register, the following ships were launched in the United Kingdom:—761 merchant ships of 1,367,570 tons (gross register) and 41 warships of 191,555 tons (displacement). British Colonies launched 70 ships of 25,000 tons. During the same period all other countries launched 509 ships of 676,000 tons. The United States had an output of 170 ships and 241,000 tons; Germany 114 ships of 168,400 tons; France 57 ships of nearly 102,000 tons. The individual production of either the Glasgow, Newcastle, or Sunderland district exceeded the total output of the United States. Belfast alone launched 16 ships of nearly 120,000 tons, and the Hartlepools and Whitby 44 ships of nearly 126,000 tons. Of the total tonnage set afloat in 1898, 70 per cent. was launched by the British Empire.

The salient facts in these returns, apart from the magnitude of the production, are the practical disappearance of sailing ships from the list of vessels launched in the United Kingdom; the almost universal employment of steel instead of iron; and the continued increase in the average size and tonnage of ships. Only 17 sailing ships were launched, averaging about 250 tons; as against 744 merchant steamers, averaging over 1,800 tons, and 41 warships, averaging nearly 4,700 tons (displacement). In 1860 the British mercantile marine included 8,242 sailing vessels of over 3,000,000 tons (net register), as against 527 steamers of 307,000 tons. At the end of 1897 the figures were 1,604 sailing ships of less than 2,000,000 tons, and 3,715 steamers of nearly 5,756,000 tons (net register). As it is estimated that the comparative efficiency of steam to sailing tonnage

is at least as three to one, it follows that, whereas the total steam tonnage of 1860 was equivalent to less than one-third of the sailing tonnage, at the end of 1897 it was equivalent to nearly nine times the sailing tonnage on the British register.

The use of iron for shipbuilding may be roughly stated to have commenced about sixty years ago. In 1850 out of 133,700 tons of new shipping added to the British register only 12,800 tons were iron and over 120,000 tons were wood. In 1860 out of 212,000 tons 64,700 tons were in iron ships. In 1868 out of 369,000 tons 208,000 tons were iron; in 1880 out of 404,000 tons 384,000 tons were iron and 20,000 tons wood. Steel was used to a very limited extent prior to 1875. In 1878 only 4,500 tons of steel shipping were classed at Lloyd's, and in 1881 41,400 tons. The total tonnage of steel ships in 1881 was less than 6 per cent. of the aggregate tonnage of iron and steel ships. In 1892 steel had reached 98 per cent.; and 99 per cent. of the new tonnage launched in 1898 was steel. Iron is now used only for trawlers and small vessels of less than 250 tons.

With the change from sail to steam and from iron to steel has come a great increase in the average size of sea-going ships; and in recent years the construction of a considerable number of very large vessels, designed either for high-speed passenger service, or for the conveyance of enormous cargoes at moderate speeds. The "Oceanic" of the White Star Line is the latest representative of the former class; and no less than six steamers of the latter class, ranging from 8,000 to 12,000 tons, were launched in 1898 in the United Kingdom.

In all these changes, as will be shown hereafter, mechanical engineering has played an important part. A close alliance between the shipbuilder and the mechanical engineer has been essential to success. British supremacy in shipowning and shipbuilding is not an accident. It has been won by the enterprise of shipowners, and by the readiness of shipbuilders to initiate or adopt improvements in materials and methods of construction, in types of ship, and in character of equipment. Forty years of continuous effort on these lines of progress have produced a mercantile marine which has been

valued by a high authority at 250 millions sterling, while its annual earnings are estimated at 80 to 90 millions. Two generations of workers have been trained since wood began to give place to iron, and sail to steam. Unrivalled experience has been acquired. We have become the shipbuilders and shipowners *par excellence* of the world. This is a proud position, which cannot be maintained without continued attention to all that makes for improvement and economy.

Foreign shipbuilders have carefully studied our methods, and in some respects may have improved upon them. It behoves us to take careful note of what is being done elsewhere, and to be ready to learn from all capable teachers. Although circumstances have changed in many respects, and in some to our disadvantage, the most confirmed pessimists have hardly dared to include our shipping interests in the lists where foreign competition has become serious or threatens soon to be so. Other nations are naturally making, and will continue to make, vigorous efforts to develop both shipbuilding and shipowning. Some of them have great natural resources in the materials for ship-construction. Judged by the favourite but often misleading method of percentages, the growth of foreign shipbuilding in Germany and the United States is rapid. Looked at in a broad common-sense way, our lead is commanding, and so far practically unchallenged. It should be maintained, if proper steps be taken to maintain it, and if both employers and workers unite in the endeavour. As our present supremacy is largely due to the development of our iron and steel industry, as well as to the great extension of mechanical labour-saving appliances in the construction and working of ships, so must the metallurgist and the mechanical engineer continue to lend their valuable aid to the shipbuilder. We should never forget the fact that in the later days of wood shipbuilding the United States—being rich in timber while we had to import largely, and having also designers who showed remarkable boldness and skill—made a bold bid for equality. In 1815 the United States possessed about half the tonnage of the United Kingdom. In 1861 they possessed nearly 5,500,000 tons of shipping, while the United Kingdom owned about 5,900,000 tons. With the change to iron,

and probably to some extent as a consequence of the Civil War, the competition died away. Now the United Kingdom owns over $12\frac{1}{2}$ millions of tons, as against about $2\frac{1}{2}$ millions of tons owned by the United States. Signs are not wanting however that our transatlantic cousins are not content with this relative standing; and we may anticipate a renewal of the old competition, which is another reason for taking heed to our methods and machinery and for neglecting no source of economy in either building or working ships.

On this occasion I do not purpose dwelling upon the remarkable improvements made in the steam-generating and propelling apparatus of modern steamships. Time is not available, nor is it desirable to make the attempt. The history of the wonderful advances made in marine engineering has been ably summarised in our Proceedings by Sir Frederick Bramwell, Mr. Francis C. Marshall, and the late Mr. Alfred Blechynden. Another chapter in this history is now nearly due, and I trust will be contributed before long by some equally competent writer. Nor can we leave unnoticed the valuable Reports on Marine-Engine Trials by our Research Committee, so ably presided over by Dr. Kennedy. It may be doubted whether any of the lines of Research promoted by the Institution has been productive of greater practical results, or more suggestive of possible improvement. While I am compelled to pass by without further notice this important section of the work of the mechanical engineer, it is only right to say that the change from sail to steam, even for the longest voyages, with all its contingent advantages, could never have been made but for the inventive genius which has economised the coal-consumption, increased the power developed from a given weight of machinery, and accelerated as well as made more regular transit across the sea.

Even with this omission, there remains a most extensive field to survey, when dealing with the influence of mechanical engineering on shipbuilding. It will be convenient to range my remarks under the two great divisions of the *Shipyard* and the *Ship*.

Mechanical Engineering in the Shipyard.

So long as wood was the principal material employed in shipbuilding, manual power reigned supreme in the largest and best equipped shipyards, including the Royal Dockyards. Machinery was used little, if at all, in the operations of shaping, fixing, combining, and fastening the various parts of ships' structures. Remarkable results were achieved under these conditions. The towering three-deckers, now serving as hulks at our great naval ports, are monuments of the constructive skill of the shipwright, based on the experience of centuries, with wood as his material and only simple hand-tools. If I may refer to my own recollections when as a lad I entered Devonport Dockyard forty years ago, it may serve to illustrate the changes that have occurred since that date in shipyard equipment. A Royal Dockyard then had its steam factory and machine shops for the repair of engines and boilers; its millwrights' shop for dealing with ship-fittings; its steam saw-mills for converting timber; its roperies with suitable machines; and special departments for block-making or other manufactures. A few steam-hammers were to be seen in the forges. Steam cranes and capstans were installed around the basins, and steam pumps were used for the docks. But, for shipbuilding proper, manual labour held its own. Individual pieces of the structure were shaped by hand, and lifted by hand-power winches, as their size and weight were not considerable. Attempts were made from time to time to introduce new machines and to diminish hand-labour. Few of these succeeded. Even in the joiners' shops wood-working machines were then but little used. One incident dwells in my memory. An experimental machine was erected for cutting out the frame timbers or "ribs" from the logs. It was ingeniously contrived to cut curved and bevelled timbers for large warships, and to relieve the sawyers from the heaviest work. After an extended trial however, in competition with the hand-sawyers, it was agreed that they could beat the machine, and its use was discontinued.

The contrast between these conditions and those now to be seen in a modern shipyard is extreme. Machinery and labour-saving

appliances abound, and are essential to rapid and economical working. With ships of increased dimensions, scantlings have become heavier, the sizes and weights of plates and bars have increased, special arrangements have had to be made for transporting and handling materials, and the power of all classes of machinery has had to be increased proportionately. In a well-equipped yard the most careful consideration is given to every step necessary in dealing with materials from their delivery up to the time when they find their places in the structures of ships. The stacks of plates and bars are so situated that the materials can be readily lifted from the trucks on arrival, or out of the depot when required for use. Travelling cranes or gantries command the whole depot. Bogies, in many cases running on light railways, convey the materials to the machine shops, furnaces, or bending slabs, where they are shaped and prepared for erection, being afterwards similarly transported to the building slips. A large number of cranes are used for handling the materials with a minimum of labour while at the machines. At the building slips also mechanical lifting appliances are freely used. Hitherto manual power has been chiefly employed in fixing and riveting together the several parts of the structure. Serious attempts are now being made to extend the use of machinery even to these portions of the work. Some of the leading firms have erected at their building slips large travelling cranes or gantries capable of moving along the length of the slips, as well as commanding the whole breadth. These locomotive lifting appliances can be used for both erecting and putting into position parts of the structure, as well as for carrying portable machine-tools. Messrs. Harland and Wolff made use of a very large installation of this kind in building the "Oceanic." Hydraulic power was chiefly employed by them, and powerful machine-riveters were used extensively, the plating being of unusual thickness. Messrs. Swan and Hunter of Wallsend, near Newcastle-on-Tyne, have adopted another plan. Shipbuilding sheds of special design have been built over the slips. These sheds give shelter to the workmen in bad weather, and facilitate many of the operations of erecting and fastening parts of the structures. They also carry a very complete arrangement of overhead electric

cranes, which travel the whole length of the slips. These cranes lift and put in place frames, beams, and plates, as well as carry certain machine-tools. At the Newport News shipyard in the United States electrical appliances have been adopted for work of a similar nature. In all these cases it is understood that the large initial outlay has been justified by experience, especially in building heavy ships. This is readily realised when it is remembered that from 7,000 to 10,000 tons of material have to be built into the largest ships of the present day, and traversed over lengths of 500 to 700 feet, as well as lifted to great heights in many cases.

Some firms are content with simpler arrangements, such as derricks with mechanical power for lifting. No doubt such devices are of real service, and they permit of easier readjustment under the varying conditions of shipyard work. Ships have grown rapidly in size, and will probably continue to do so. With more elaborate and permanent appliances there is a difficulty in foreseeing what margin should be provided, beyond the maximum requirements of the period when the appliances are designed. In the Royal dockyards, for example, and in some private yards, where sheds existed over building berths, they have had to be removed in order to provide for ships of unprecedented dimensions. I have seen cases where ordinary sheer-legs, with mechanical power for hoisting, have been found more useful for fitting armour-plates on the sides of a battle-ship than travelling steam-cranes. Facts of this nature however in no way contradict the general principle that well-considered lifting appliances are of great utility in building ships.

In the early days of iron shipbuilding the machine-tools of shipyards were comparatively few and simple, mostly borrowed from boiler-shop practice. Since then shipyard machinery has been greatly specialised, and reconstruction of plant has become necessary from time to time, in order to meet changed conditions. At first steam power alone was used. Now hydraulic, electrical, and pneumatic power are used as allies of steam power or substitutes for it.

One of the most notable hydraulic installations was described by M. Berrier-Fontaine in a valuable paper contributed to our Proceedings (1878, page 346). It was designed by one of our members,

Mr. Ralph H. Tweddell, and was set up at Toulon in the French government dockyard. Hydraulic power as a rule finds its most general use in cranes and other lifting appliances, as well as in powerful presses used for flanging, "joggling," punching out lightening holes, and other heavy work. It is also used for riveting work that can be brought to the machines, and to a limited extent for portable riveters.

Electrical power is being extensively used in some of the best equipped shipyards, apparently with satisfactory results. It is probable that it will be much more extensively employed before long. For large machines with separate motors, and for groups of smaller machines, electric driving has much to recommend it. For operations that have to be performed *in sitû*, portable electrical machines are found most useful. As examples reference may be made to electric drills, planers for wood decks, cutters for large holes in plating on sides or decks, caulkers, and riveters. In some cases, especially in elaborately fitted warships, it is found advantageous to establish on board temporary machine-shops, which can be most conveniently driven by electric power. Many operations are thus rapidly and economically performed, which would otherwise necessitate the transport of fittings to and from shops in the yards. Portable electric-light apparatus for use on board ships while building is now generally recognised to be advantageous and economical. The arrangements made for lighting are readily extended to include driving the machines above mentioned.

Pneumatic power has not been much used in shipbuilding. It has found employment however for such operations as caulking and riveting. Mr. Babcock of Chicago has recently published the results of his experience with pneumatic riveters, and he is strongly of opinion that they can be advantageously adopted for work at the ships. As a rule nearly all such work is done by hand, although machine-riveting is largely used for work that can be taken to machines. Every shipbuilder would be glad to have a light and satisfactory portable riveting machine, which could be used in all the varying positions and conditions occurring in shipwork. Many attempts have been made to find a mechanical substitute for the heavy manual labour involved in satisfactorily "closing" and riveting shell

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and deck plating. If this can be done, there should be a considerable economy in cost, and many disputes with workmen would be avoided. As yet success has not been attained, except with special appliances: such as have been described as erected by Messrs. Harland and Wolff for carrying hydraulic riveters, or others used for riveting garboard strakes and keels. I have seen steam riveters and electric riveters under trial, and now good things are said of pneumatic riveters. Here is an opening for the mechanical engineer, who should master the essential conditions by careful observation of shipbuilding practice, as a preliminary to his design of a suitable riveter.

In all branches of engineering it is essential to economy of production that the manufacturer should furnish materials of the dimensions and forms best adapted to combination in the structures to be produced. In floating structures such as ships, economy in weight, with adequate provision of strength, is of the highest importance, resulting in corresponding addition to carrying power and earnings. Even if economy of weight has to be obtained by increased first cost of materials, it is, as a rule, well worth having; and in many instances carries with it savings in the cost of construction. The principle is sound enough, and has long been recognised, especially in warship-building. With iron as the material, it had not nearly the same range of application as is now possible with steel. Special sections of bars and beams are readily produced in steel, which were hardly obtainable in iron. Z bars, H bars, channel bars, T bulbs, angle bulbs, and other sections, have come into general use, taking the place of built-up combinations of plates and angles with rivet connections. Economy in weight and labour is thus obtained; but special appliances are needed for working some of these special sections. With steel much larger plates are produced, and riveting is lessened. In the "Oceanic" the majority of the plates in the central portion of the vessel are said to be each over 28 feet long, about 4½ feet wide, and from 2 to 3 tons in weight. Iron plates of 12 to 14 feet in length and 3 to 4 feet in width would have been considered of large dimensions, and the riveting work in butts and edges would have been proportionately greater than with the larger steel plates.

The shipbuilder is under great obligations to the steelmaker for this progress in manufacture; but the mechanical engineer has had a hand in its achievement, by designing and making the machinery and plant used in the steel-works. In the device of new and more powerful machines for the shipyard his work has been more obvious. Without such machines the superior working qualities of steel could not have been utilized as is now done. Operations are now commonly performed on steel plates in a cold state that were not possible with the best qualities of iron. Flanging is extensively practised, to form stiffeners or to make connections such as were usually formed in iron ships by riveting angles on plates. The edges of skin-plating and deck-plating are "joggled," and the use of "liners" or "packing pieces" is avoided. Steel plates are bent and worked to difficult forms necessary in certain parts of ships, where castings were formerly used. Lightening holes are punched out of comparatively thick plates, and in many other ways weight and cost are reduced by the use of special machines. Many of these are worked by hydraulic power, and it is difficult to imagine a better application of that power than is seen in modern flanging and punching machines.

In concluding these remarks on shipyard machinery it may be of interest to enumerate briefly some of the principal machines now in use.

Flanging Machines.—Capable of flanging cold at one stroke plates up to 33 feet in length and $1\frac{1}{4}$ inch in thickness. Less powerful machines are used for thinner plates up to $\frac{3}{4}$ inch. Most of these machines are hydraulic.

Joggling Machines.—Capable of dealing with plates up to 1 inch in thickness; also with angle bars. Most of these machines are hydraulic.

Shearing Machines.—Capable of shearing plates up to 2 inches in thickness; and of dealing with Z bars and angle bars. These very thick plates occur in the protective decks of warships.

Punching and Lightening Machines.—Capable of punching at one stroke large lightening holes out of plates 1 inch thick. Also of punching rivet-holes in plates up to $1\frac{1}{2}$ inch thickness. A few can punch up to 2 inches thickness.

Bending Rolls.—Capable of bending plates 30 to 35 feet long and $1\frac{1}{2}$ inch thick.

Straightening Rolls.—Capable of dealing with plates 7 feet wide and $1\frac{1}{2}$ inch thick.

Planing Machines.—Capable of dealing with plates up to 35 feet long, or batches of plates. Some of these machines plane edge and butt simultaneously.

Bevelling Machines.—Capable of dealing with angle-bars and Z bars while hot.

Radial Drills and Countersinking Machines.—Fitted with revolving arms 8 feet long, traversing through 180 degrees: capable of drilling holes up to 3 inches in diameter, or much larger holes with special cutters. Countersinking machines can deal with 700 to 1,200 holes per hour, according to thickness of plates.

Most of the larger shipyard machines are now fitted with hydraulic lifts and cranes for dealing with the plates &c. while they are at the machine, and lifting them on and off the bogies or trucks on which they are transported through the yard.

Mechanical Engineering on board Ship.

The development of mechanical appliances for the equipment and working of ships during the last forty years is no less remarkable than that which has been briefly sketched in connection with shipbuilding. At the earlier date, apart from the propelling machinery, manual power only was employed in the largest and best found ships. Work on masts and sails, steering, loading and unloading cargo, lifting and lowering boats was all done by hand-power, aided by simple mechanical appliances. In warships the armaments were hand-worked; gun-carriages, training gear and ammunition-supply were all of the simplest character, and practically unchanged in principle as compared with those which had been used for centuries. Our first sea-going ironclad, the "Warrior," laid down in 1859, may be taken as an example of the best practice at that time. In the original design steam-power was applied, apart from propulsion, only to pumping and ash-hoisting. The pumping was

done partly off the main engines, and partly by an auxiliary engine added during the building, which also worked the ash-hoisting gear by means of chain and spur gearing. A full equipment for sailing was provided; all the work in this department was done by hand. When the vessel sailed, the screw propeller was raised out of water in its banjo frame. A weight of 32 tons had to be lifted, and this was done by means of special purchases. In working spars and boats the heaviest weights dealt with were from 5 to 6 tons. Steering was a formidable operation. Between the steering wheels and the tillers there was a multiplication of tackles to gain power, and at full speed forty or fifty men worked at the wheels and relieving tackles, even then moving the rudder very slowly, and to moderate angles. Heaving in anchors and cables was a slow and laborious operation, accomplished by fitting capstans on two decks and crowding men on the bars.

In the mercantile marine the conditions were very similar. Cargo steamers were equipped with hand-worked appliances for loading and unloading. The winches were similar in character to those used from early times in sailing ships, the lifting power being moderate, and working slowly except with light loads. Hand-power was used for cable work, steering, and working spars and sails.

Now the conditions of working are entirely changed. Mechanical power is extensively employed, manual power is minimised, comfort and habitability are enormously increased, steering is made easy in the largest and swiftest vessels, loading and unloading of cargoes are accelerated, anchors and cables are worked safely and rapidly by a few men. Without entering into details it may be interesting to glance at a few of the principal applications of mechanical power, and their influence on the working of ships.

Steering.

Steering naturally takes the first place. In the introduction of efficient steam-steering appliances, one of our Members, Mr. Macfarlane Gray, has played a distinguished part (Proceedings 1867, page 267). From him I learn that the first steps were in 1866, as the result of

difficulties that had occurred in steering the "Great Eastern," and on the suggestion of the late Sir James Anderson, who was the commander of that ship. Mr. Gray's invention of the differential gear enabled the steering engine, when placed at a distance from the navigating station, to be controlled by the movement of the steering wheel: so that the helm could be made to follow, and assume any desired position. The first trial on the "Great Eastern" was made in March 1867, and proved successful. It led eventually to the general adoption of steam-steering gear, although some time elapsed before the full advantages were realised. The Admiralty took the system up on the recommendation of Sir Nathaniel Barnaby, and applied it to the "Minotaur" class—the longest warships then afloat—where difficulties in steering by hand had occurred. No better illustration could be given of the advantages of steam-steering than are afforded by the trials of the "Minotaur." With manual power eighteen men were employed at the wheels and sixty at the relieving tackles. They took $1\frac{1}{2}$ minute to put the helm over to 25 degrees, and $7\frac{2}{3}$ minutes were occupied by the ship in turning through 360 degrees. After steam-steering was adopted, two men at the wheel put the helm over 35 degrees in 16 seconds, and the ship turned in $5\frac{1}{2}$ minutes and in two-thirds the space. For all ships such a gain in manœuvring power is of immense value; for warships the utmost handiness is essential, and their rudders are proportionately much larger and more difficult to work. No wonder therefore that nearly all steamships are now fitted with mechanical steering gear: mostly steam, in some instances hydraulic, and in a few recent ships electrical. Many arrangements have been devised subsequently for effecting the same object as was attained by Mr. Gray. Some of these are remarkably ingenious. It is but right however that he should have the credit of being the pioneer in this important change.

As an example of the latest practice in the Royal Navy, it may be stated that in a first-class battleship or cruiser there are two independent steering engines, each of which can move the rudder through 70 degrees in 30 seconds when steaming at 18 to 23 knots. The maximum turning moment on the rudder head, in the case of a battleship steaming at 18 knots, is estimated at 450 foot-tons.

Proposals have been made, and some of them have been worked out in detail, for automatically steering ships on a given course. While this is a mechanical possibility, the plan has not found favour in practice, nor is likely to do so. Under the actual conditions of navigation there is obviously a constant need for human watchfulness and control; while the maximum economy obtainable by the use of such automatic steering gear is comparatively unimportant.

Capstans, Windlasses, and Cable Gear.

Manual power has practically ceased to be used for working anchors and cables in steamships. Steam power is generally employed, hydraulic power has been used in some cases, electrical power is coming into use. Anchors and cables in the largest ships are too heavy to be satisfactorily dealt with apart from mechanical appliances, and in smaller vessels similar appliances economise labour. These appliances have to be devised in such a manner as will fit them to withstand sudden and severe shocks and stresses inevitably occurring in service; while they must be capable of controlling the cables when at anchor, or when mooring or unmooring. The details of the mechanism in modern capstans and windlasses show great ingenuity, as well as capacity for standing rough usage. The engineering firms who make a speciality of the design and manufacture of these appliances deserve great credit for what they have accomplished.

In the Royal Navy it is the practice to fit capstans so that they can be worked either by hand or by power. Taking a large battleship of 15,000 tons, the forward capstans have to deal with $2\frac{9}{16}$-inch cables, weighing 16 tons for each 100 fathoms, and with anchors each weighing 6 tons. It is required that these capstans shall be capable of lifting 35 tons at a speed of 25 feet per minute; and this is practically tested in each ship.

In the largest classes of merchant steamers, cables up to $3\frac{1}{4}$ inches are now used; whereas thirty years ago there were few vessels with more than $1\frac{3}{4}$-inch cables. The speed of lifting the anchors does not usually average more than 40 feet per minute.

Ventilation.

Artificial ventilation, chiefly by means of fans, is now largely employed in many classes of ships, and especially in warships. The arrangements include both supply of air to the stokeholds and furnaces, and supply to the living spaces. In some instances the living spaces are dealt with by exhaust fans, a natural supply of fresh air being depended upon. Perhaps the greatest demands arise in connection with the general adoption of systems of mechanical draught to stokeholds and furnaces, supplementing the funnel draught. All these requirements affect the work of the mechanical engineer, leading to the construction of new types of fans and fan-engines.

Electrically driven fans are now coming into extensive use on shipboard, and are an excellent application of that form of power. Cases have often occurred in warships where the introduction of a steam-driven fan for the purpose of ventilating a compartment situated low down in the hold and containing machinery has been of doubtful benefit. The effect of a better air-supply has been almost neutralised by the additional heat caused by the fan-engine and its steam connections. With electricity, difficulties of this kind can be avoided and other simplifications made, including smaller air-shafts, better maintenance of watertight subdivision, and less waste of power.

Warships, with their complicated subdivision, armament, and protection, present the most difficult problems. In them it is necessary to provide for ordinary conditions of navigation or service in very varying climates, as well as for the special condition where they are in fighting trim, with all the hold spaces below the protective deck closed down, and most of the doors in watertight bulkheads also closed. As an example of recent practice, not the latest, it may be stated that in a first-class battleship, outside the machinery and boiler spaces, there are fifteen 24-inch fans driven by electric motors, each fan being capable of delivering 1,500 cubic feet of air per minute at the end of its air-trunk. In the boiler rooms there are ten fans $6\frac{1}{2}$ feet in diameter, driven by open double-acting steam engines; and in the engine rooms two similar fans.

Passenger steamers of high speed are commonly fitted with powerful ventilating appliances both for living spaces and for machinery and boiler spaces. In these vessels the conditions are simpler than in warships. Cargo steamers also require careful treatment as regards ventilation, especially with certain kinds of cargo, such as coals and oil.

Internal Lighting.

In all classes of steamships electric lighting is becoming the rule, and no better evidence of its advantages need be required. While it is most desirable in living spaces, it is practically essential to good working and efficient maintenance of machinery. For ship purposes, special water-tight fittings are desirable. In other respects the installations present no special features requiring mention. In warships the "search-light" fittings are of a powerful character. In merchant ships less powerful lights suffice.

It is probable that the general adoption of internal electric lighting will tend to a wider use of electrical power for many auxiliary purposes. A notable effect on the working of all classes of ships has been produced by the introduction of electric lights. The passage of the Suez Canal is now made by night as well as by day: ports are entered and left at night with safety: and coaling, loading or unloading, &c., proceed unchecked. In many other ways economy and speed of working are promoted.

Pumping.

Mechanical power is now universally employed for pumping purposes in steamships. A few hand-pumps may be fitted, but they are used only in exceptional circumstances or for special work. Steam-driven pumps are generally preferred. Pumps driven by electro-motors are now coming into use. For the ordinary service of ships ample pumping power is provided. In merchant ships, where water-ballast is commonly used with economical results, the pumping arrangements are specially arranged for rapidly clearing the ballast-tanks. Oil-carrying steamers have powerful pumps for dealing with their liquid cargoes.

While ample pumping power is desirable and of service in many circumstances, it is now generally agreed that the best protection against foundering is good watertight subdivision of the hold-space. The undue development of pumping power with a view to dealing with serious injuries from grounding or collision is admitted to be undesirable, since it is hopeless to attempt to meet a serious leak by pumping when there is free communication with the sea.

Lifting Appliances.

In no department has the equipment of modern ships received greater development than in lifting appliances. One of the most marked tendencies in recent construction has been increase in the size and carrying power of ships. Unless there had been a corresponding development in the means of dealing with cargo, this increase of size could hardly have occurred, and the advantages resulting therefrom would not have been realised. It is a principle in ship-designing that, as ships increase in size, the expenditure of power and fuel for a given speed becomes relatively less, and the "useful displacement" or "carrying power" becomes relatively greater. In other words, as far as sea transit is concerned, the ratio of earnings to expenses in the larger ship should be greater than the corresponding ratio in the smaller. On the other hand, it is well recognised that, unless there is quick despatch in loading and unloading cargoes, serious diminutions of earnings must result from the longer detention in port. Hence it follows that, for the complete commercial success of the larger classes of cargo carriers, lifting appliances of the most efficient character and of ample capacity are of the greatest importance. The prevision of the shipowner, in collecting the cargo and having it ready to load, would be ineffective unless the mechanical appliances were adequate.

Remarkable progress has been made by mechanical engineers in meeting these demands. Certain firms have made a special study of lifting appliances on board ship; and I owe the following summary of progress to my friend Captain Chapman, the head of one of these firms. Thirty years ago most cargo steamers were fitted with hand-power

crabs or winches, similar to those long used in sailing ships. Then came the fitting of engines to winches of the old pattern, the engines being placed diagonally. To reduce the strains on decks, and facilitate working and repairs, horizontal steam-winches were introduced. For many years these winches had cylinders not exceeding 5 or 6 inches in diameter with 10 inches stroke. The lifting barrel was about 10 inches in diameter, and took the cargo chain-runner. Two warping drums were fitted on the slow-speed shaft, while the quick-speed shaft carried "whipping" drums. Until twelve years ago four or five such winches formed the lifting equipment of a cargo steamer. Now in the largest steamers from twelve to twenty winches are fitted, besides cranes. Winches have cylinders from 7 to 10 inches diameter. They are fitted with large barrels and outer drums on the slow-speed shafts, as well as smaller drums on the quick-speed shafts. By this means five drums are made available on each winch, and by suitable arrangements of "spans" from mast to mast with falls attached, forty to fifty whips for lifting light loads may be kept going simultaneously by eight or nine winches. Steam is turned on to the winches, and they run all day except at meal times. As a rule light loads, say from 2 to 3 cwts., are thus dealt with. Heavier loads can of course be dealt with by different arrangements, say up to 6 or 7 tons.

Besides the winches, derricks are extensively used for lifting, being carried by the masts or by derrick posts. Cranes, standing upon the decks, are also largely used.

Great care is bestowed upon the details of all these appliances, in order to economise power and increase rapidity of working. With higher steam-pressures this is a most important matter, and considerable variations of pressure have to be provided for.

Cargoes of a special character—such as coal, ore, grain, and oil—require to have special arrangements made for both loading and discharge. Bulky materials, such as cotton, require to be compressed into the narrowest possible limits for storage in the holds of ships. Here again the mechanical engineer has played an important part. It is not possible nor desirable for me to dwell upon the details of coal shipping, grain elevators, ore piers and shoots, oil pumps and

storage, important as these are to the successful working of many classes of ships. American engineers have undoubtedly shown the way in many directions, quickened no doubt by the high price of labour in the United States. British engineers have done great things also, and must not always expect to be leaders in improvement, nor should they be adverse to benefiting by the work of others. In fact they must take care that British shipowners continue to have at their command the most perfect appliances for loading and unloading cargoes.

As an example of present conditions I may present the following facts, which I owe to the kindness of my friend Mr. Thomas Ismay of the White Star Line. The "Cymric" is an excellent example of a modern cargo-steamer. Her measurement capacity is about 19,400 tons, her dead-weight capacity about 12,000 tons, excluding coal. Her cargo space is divided into seven holds, each of which is subdivided into three compartments, namely 'tween decks, orlops, and lower hold. Five of these compartments are fitted as refrigerators, with a total capacity of about 2,200 tons. There are 9 hatchways, 15 derricks, 17 steam winches for cargo purposes, and mast-head "spans." The capability of these appliances is illustrated by the fact that she has commenced discharging a full cargo at 7 a.m. on Monday, completed her loading of cargo and taken on board 1,600 tons of coal, and undocked at noon on the following Friday. Loading and unloading were carried on to a great extent concurrently, about 400 to 450 men were employed, and the average rate of discharge was not less than 300 tons (weight) per hour, the corresponding rate of loading being about 250 tons. All the general cargo, apart from bulk-grain &c., was weighed at landing. When it is remembered that in such a general cargo there may be 30,000 to 40,000 packages to be dealt with, these results are evidence of both excellent mechanical arrangements and perfect organization.

The Hamburg American S.S. "Pretoria" has 14 powerful steam winches, 8 steam cranes capable of lifting 3 tons each, and is so fitted that about 40 lifts can be undertaken simultaneously.

Steam power has been principally employed hitherto for these lifting appliances. Hydraulic power has been used to a limited extent, but with complete success. Electrical power is now applied in some cases, and will probably be more extensively used in future.

Refrigeration.

This is one of the most recent, and at the same time one of the most important applications of mechanical engineering on board ship. It is not yet twenty years since the frozen-meat trade was begun between Australia and England. At the outset comparatively small cargoes were carried; but as machines were improved and experience was enlarged, so larger cargoes were carried, and a new branch of the shipping industry was created. Sir Alfred Haslam, who has done so much to develop this branch of mechanical engineering, has at my request given me some interesting facts. The first refrigerators were designed to deal with 150 tons of meat. Now machines are constructed capable of dealing with 3,000 tons, while they occupy only $2\frac{1}{2}$ times the space and consume about three times the coal required for the first machines. In 1881 about 14,000 carcasses were brought to this country from the Colonies; in 1899 it is anticipated that from 8 to 9 millions will be delivered from the Colonies and various parts of the world. In addition to dead meat, large quantities of butter, fruit, and other perishable cargoes, are now carried from the far ends of the earth, and delivered in good condition. Thanks to the enterprise of the shipowner and the ingenuity of the mechanical engineer, the British Empire is becoming self-contained and self-supporting, since the natural products of all parts of the Empire suffice to meet all needs, and the cost of conveyance across the sea is minimised by the skill of the shipbuilder and the marine engineer.

Time does not permit me even to touch upon the relative merits of various types of refrigerating machines. Cold-air machines were first used, and still find favour for use on board ship. Ammonia compression machines and other chemical machines are also used.

Nor can I do more than allude to the enormous scale to which cold storage on shore has grown. The first stores at the London Docks held about 400 tons of meat, or 16,000 carcasses. Stores now being completed at the Victoria Docks will hold about a million carcasses. The first refrigerating machine used in connection with these stores in 1880 was equivalent to the melting of 21 tons of ice

in twenty-four hours. A machine is now in construction which has about tenfold as great power.

All who travel by sea know how much health and comfort are promoted by the change in dietary made possible by refrigeration. In recent years refrigerating chambers have become a part of the equipment of the larger classes of ships in the Royal Navy. Two machines are usually fitted, each of which has to be capable of reducing the temperature of a chamber of 1,800 cubic feet capacity to 15° Fahr., and of easily maintaining this temperature when the atmosphere and sea-water are at 100° and 85° Fahr. respectively. The atmosphere in the chamber must also be kept perfectly dry.

Mechanical Engineering in Warships.

The auxiliary machinery of warships necessarily has much in common with the corresponding machinery in merchant ships. There are however many special requirements arising from their armament and equipment as fighting machines; and hence it happens that in warships the applications of mechanical power reach their fullest development. Modern warships are sometimes styled "boxes of machinery," and the description is not inapt. The tendency is, in fact, to multiply machines and to minimise manual labour, to an extent which is not universally approved. On the other hand, with modern armaments and equipment, an extensive use of mechanical power is inevitable, and the expenditure of fuel on auxiliary services grows greater in proportion to that devoted to propulsion.

Ten years ago, in a first-class battleship of 12,000 H.P. (maximum) for the propelling machinery, there were fifty auxiliary engines capable of indicating in the aggregate about 5,000 H.P. if they all worked simultaneously, which of course they did not. Today a similar statement would show a growth in the auxiliary power as compared with the propelling.

The multiplication of auxiliary services makes serious demands upon the coal supply of warships. Even in harbour the expenditure of coal is large on lighting, distilling, ventilation, air-compression, drilling with the heavy guns, and other services. From 10 to 25 tons a day may thus be expended in a large battleship or

cruiser of high speed. As warships cruise at low speeds and spend much time in harbour, it results that, taking the year through, fully as much coal is burnt for auxiliary services as for propulsion. Coal endurance being one of the most important factors in warship efficiency, facts such as these have tended to cause a doubt as to the wisdom of more widely extending mechanical appliances. It is pointed out that manual power with simple fittings, such as can be readily replaced if damaged in action, can compete with mechanical appliances in many directions; and that it is better to have larger crews in fighting ships, so as to provide a margin for inevitable casualties, than to use the alternative of labour-saving machines liable to derangement or injury and not easily repaired in action. The practical solution of the problem clearly lies in the due proportion being found between manual and mechanical appliances.

Gun construction in its modern form is largely dependent upon mechanical engineering. Our Past-Presidents, Lord Armstrong and the late Sir Joseph Whitworth, were famous as mechanical engineers before they undertook the design and manufacture of guns. In this Address however, the story of progress from the smooth-bore cast-iron 68-pounder, weighing 95 cwts., to the 110-ton breech-loading rifled gun, firing 1,800-lb. projectiles, can find no place. Nor can more than a brief glance be bestowed upon the interesting work done by the mechanical engineer in regard to appliances for mounting, working, and loading modern guns, supplying the ammunition, and securing rapidity and accuracy of fire with a minimum of labour.

Anyone who will study the breech mechanism and mounting of a hand-worked quick-firing gun will discover a triumph of mechanical engineering over a special and difficult problem. Take for example a 6-inch quick-firing gun of the latest naval pattern. The gun weighs about 7 tons, fires 100-lb. projectiles with a muzzle velocity of nearly 2,800 feet per second, and with an energy of 5,370 foot-tons, corresponding with a penetration of 22 inches of wrought-iron. Its breech mechanism is so devised that four or five aimed shots can be fired per minute. Its mounting is so arranged that the gun can be easily trained, elevated, or depressed by one man. The great energy of recoil is perfectly controlled, and the crew numbers

only four or five men. If such a gun is compared with the 68-pounder smooth-bore muzzle-loader, which I well remember, mounted on a wood truck carriage, with rude arrangements for elevating, and still ruder for training and controlling recoil, a striking illustration is obtained of the progress made in forty years with hand-worked guns.

When we pass to heavier guns worked by mechanical power, a still greater contrast appears. The 110-ton gun of $16\frac{1}{4}$ inches calibre has charges of 960 lbs. of powder and 1,800-lb. projectiles. Fired with a velocity of 2,100 feet per second, these projectiles have an energy of 54,000 foot-tons, with an estimated penetration of 37 inches of wrought-iron. Obviously manual power alone would be unequal to working such guns. The mechanical engineer has devised suitable machinery which enables pairs of guns, mounted in a thickly armoured turret, to be loaded, trained, elevated, and depressed with ease and comparative rapidity under the guidance of a few men. Mr. George Rendel was probably the first, as well as one of the most successful, designers of mechanical appliances for working heavy guns by hydraulic power. Messrs. Armstrong have from the first taken a leading position in this class of work. Messrs. Whitworth, and in more recent times Messrs. Vickers, have also undertaken it on a large scale. Hydraulic power finds most favour in the Royal Navy. Abroad electrical power is now extensively used. Pneumatic power has been employed in a few cases.

Improvements in gun-design and in explosives have resulted in an increased ratio of power to weight in the latest types of guns. As a result in the latest completed battleships, guns of 12-inch calibre, weighing 46 tons, firing 850-lb. projectiles, with muzzle velocities of about 2,400 feet per second, and energies of 33,000 foot-tons have been used, instead of the 67-ton and 110-ton guns of earlier date. These reduced weights of charges and projectiles are more easily handled; and this fact, together with certain changes in the system of mounting, have enabled many of the operations of loading and working the guns to be performed by manual power as well as by hydraulic power. This duplication is obviously advantageous, and reduces greatly the risk of heavy guns being put out of action. There was a time when a return to guns of still smaller dimensions,

capable of being worked exclusively by hand-power, was strongly advocated. It was urged that it was unwise to depend at all on mechanical power, because it might fail at a critical moment. Such arguments are now but little heard. Experience does not demonstrate that any serious risk of breakdown need be feared in mechanical appliances. Moreover the advocates of manual power overlooked the fact that, supposing their system had been adopted, there must still have remained in all modern mountings and breech mechanisms many comparatively delicate parts, perhaps more liable to injury or derangement than the appliances which were objected to.

Steady improvement has been made in heavy gun mountings and in rapidity of fire. For example, with 12-inch guns from $2\frac{1}{2}$ to 3 minutes were formerly considered to be a reasonable interval between successive rounds, and in foreign navies twice that time was not thought too much; now the interval has been brought below 1 minute, when pairs of guns are loaded and fired. Loading has also been made possible with the guns in any position; whereas formerly the guns were brought to fixed hoists, and to a definite angle of elevation for loading. It is most interesting to watch the working of these heavy guns, by means of mechanisms controlled by a few men. All the operations are performed with rapidity and precision, from the moment when projectiles and charges are moved from their stowing positions in shell rooms and magazines situated deep down in the holds, up to the time when they are rammed home in the gun, the breech closed, and the gun made ready for firing. Then the captain of the barbette or turret is seen training or changing the elevation of the gun up to the instant when he fires by electricity, and the huge projectile is discharged.

Passing from guns to torpedoes, we find a fresh example of the important work done by mechanical engineers. The inventor of the automobile torpedo, Mr. Whitehead, is an eminent member of the profession. The torpedo itself is a beautiful example of mechanical engineering. All the machinery connected with air compression and storage, all the arrangements for ejecting above or below water, involve skilful mechanical design. Nor is this all. From the introduction of the torpedo has sprung the necessity for special

structural and defensive arrangements in warships; as well as the construction of the swift torpedo flotilla-boats, destroyers, gunboats and depot ships, whose performances are not merely remarkable, but suggestive of possibilities in regard to steam navigation at high speeds.

The smaller classes of boats using the locomotive torpedo have to be carried by warships. They weigh, fully equipped, 18 to 20 tons; or about three times as much as the heaviest load ordinarily dealt with in merchant ships by their own lifting gear. This has involved the design of special lifting appliances for warships. After long experience in the Royal Navy the most suitable arrangement has been found to be a strong steel derrick carried by the mast, with powerful steam or hydraulic hoists working tackles which lift the boats and top the derrick. Winches or capstans are also used in some instances for swinging the derricks. Admiralty specifications require that the lifting gear shall be capable of dealing with a load of about 18 tons lifted by a single wire-rope, as well as with a load of 9 tons raised 30 feet per minute. In one ship, the "Vulcan," built as a torpedo-depot ship and boat-carrier, instead of derricks two powerful hydraulic cranes are fitted (Proceedings 1892, page 247). She carries six steel torpedo-boats 60 feet long and of 16 knots speed, besides sixteen other boats, some of large size. The total weight of these boats is 150 tons, and they are placed 27 feet above water. The two cranes and their gear weigh 140 tons; the tops of the cranes are 55 feet above water. It required careful designing to meet such exceptional conditions satisfactorily, and to produce a stable and seaworthy ship. She has now been many years on service, and has a good reputation.

Besides these special boat-lifting appliances, warships commonly have special coal-hoists, transporters, and other gear for the purpose of accelerating the taking of coal on board. Rapidity in coaling must be of great importance in time of war; and keen competition between ships in the various squadrons as to the rates attained has led to great improvements in details of gear, as well as to remarkably rapid coaling becoming the rule in the Royal Navy. Recently at

Gibraltar the "Majestic" took on board 1,070 tons of coal in 6 hours and 10 minutes—a very fine performance.

All the larger ships in the Royal Navy have engineers' workshops fitted with a considerable number of machine-tools, which are driven by power, and are of sufficient size to deal with ordinary repairs. The "Vulcan" is a special vessel in this sense also, as she has an exceptionally well-equipped workshop, a small foundry, and a hydraulic press for forgings. For repairs of the boats she carries, or for those of torpedo-boats and destroyers in company, or for certain repairs to ships of the fleet to which she is attached, she has been found most useful. Besides being a floating factory and a boat carrier, she has a large torpedo and mining equipment and an electrical laboratory, and serves as a school of instruction for mining and torpedo work. In addition she is a swift cruiser, with a fair armament and well protected. As an armed ship she represents the fullest application of mechanical appliances afloat. Her construction was commenced in 1887. Other navies have since imitated her.

Another "Vulcan" was fitted up as a floating factory to serve with the American fleet during the recent war. She was originally a merchant steamer, but is said to have proved of great service. Naval opinion seems to favour the use of vessels of this class with fleets. It is held moreover that no modern fleet can be considered to be complete, unless the fighting ships are supplemented by ships specially equipped for distilling and storing fresh water, or carrying coals, ammunition, and reserve stores.

This rapid review of the intimate and extensive connection between mechanical engineering and the building, equipment, and working of ships, has much exceeded the limits I desired to impose, and I fear will have exhausted the patience of my hearers. Even now it is imperfect and incomplete. Enough has been said however to place beyond doubt the correctness of my preliminary statement that the alliance of the shipbuilder and the mechanical engineer has been of immense advantage to our great shipping interests. Since the maintenance of our supremacy on the sea, in both warships and merchant ships, is of vital importance to the Empire, may I not venture in conclusion to assert that the members

of this Institution, and of the profession it represents, have deserved well of their country by aiding its remarkable maritime developments?

Sir Edward H. Carbutt, Bart., Past-President, said the privilege devolved upon him, as the senior Past-President present this evening, of fulfilling the duty of moving a vote of thanks to Sir William White for the able and instructive address he had delivered. As to a great part of this duty he had been anticipated by the frequent applause which had greeted the President during the course of his address and at its conclusion. At the beginning of the address allusion had been made to Robert Napier, the eminent shipbuilder. Though he had been President of the Institution for three years in succession (1863–4–5), he had once made a remark to the effect that he would rather build a fleet of ships than make a speech. The present distinguished occupant of the presidential chair had shown how ably he could design a fleet of ships; and all who had attended the Institution dinner yesterday evening had heard how good a speech he could make; while the present audience could testify how deserving of the most careful consideration was the address to which they had just listened. Sir William White he believed was rightly looked upon as one of the most remarkable men in England, or in Europe, at the present time. He had designed nearly the whole of the more recent ships in the existing British navy—at any rate, all those which had been built, or were now being built, for the re-construction of the navy; and those ships which had not been designed by him would not be able, he feared, to give so good an account of themselves in any battle in which they might be called upon to engage. Not only had the most powerful warships of modern times and the most powerful cruisers been designed by Sir William, but he had also designed some of the torpedo-boats and torpedo-catchers and ships for carrying coal; and in addition the "Vulcan," which was really a floating engineering factory at sea, and

moreover carried, besides all her engineering appliances, a large number of boats for the benefit of the fleet. All this work had been done by Sir William White under great pressure. It was not as if unlimited time had been allowed him; but the nation looked to him to design their ships and get them ready in the least possible time. It was indeed remarkable that the most magnificent fleet which any nation in the world possessed—in fact the finest fleet which had ever been seen—had been designed in such a short time, and without a single failure worth mentioning. It was said that every man of energy met with failures; but no one could point to any ship as a failure which had been designed by Sir William White. No doubt complaints were sometimes heard of a piston valve having gone wrong, or a tube in a boiler having leaked; but amid such vast masses of machinery as had to be dealt with in the ships of the navy it could not be expected that everything would go on without an occasional hitch. Although he did not suppose any one objected to fair criticism, for which indeed sensible persons were thankful, yet he thought that many of the questions asked in the House of Commons had often been only carping criticisms, which had done no good. The Admiralty he was happy to believe had come well out of the ordeal; and if any body of men deserved the thanks of their country at this time he considered it was the Admiralty; and if any man connected with the Admiralty deserved the thanks of the nation it was Sir William White, who had done the Institution the honour of becoming their President. He therefore invited the members to join him in according the sincerest thanks, not only of the Institution, but of the whole mechanical world of England and the empire, to the President, Sir William White, for the address he had delivered this evening.

The Right Honourable William James Pirrie, Member of Council, was glad to know that it was one of the privileges of a junior Member of Council to second the vote of thanks. He took this opportunity of assuring the members how highly he appreciated the honour; and he had to thank them for electing him to the Council, as one of the first Irishmen, he believed, who had ever had a seat on

(The Right Hon. W. J. Pirrie.)
the Council of the Institution of Mechanical Engineers. He also felt much gratified by the kindly reference which in the course of his address the President had made to his own firm in Belfast, in regard to the efforts they had made, not only towards producing the largest ship that had ever been built, but also in adopting some of the many mechanical appliances so rightly mentioned as a necessity for the construction of large ships. The only matter that he thought had possibly not been noticed in the President's hurried visit to the ship-yard in Belfast many years ago was the pneumatic riveting, which had been used there very largely indeed for the last ten or twelve years for the lighter class of work; it was only for larger sizes of plates and rivets that hydraulic riveting was used. What Sir Edward Carbutt had said of the President made him feel relieved to think that he was not a competitor in the designing of the merchant navy. He did not know that he could pay the President a greater compliment than to say that he and others of his profession should dread having Sir William White as a competitor in the designing of merchant vessels. In the merchant service however, no less than in the navy, the designers aimed at continual progress; and no sooner had his firm got a ship just ready for sea, and the trial trip finished, than they told the owners that they saw many mistakes in her, which they could avoid if they were given another opportunity. The navy of the country he was sure, and certainly the mechanical engineers, should feel proud indeed that this Institution had such a President as Sir William White. He seconded the resolution with the greatest pleasure, and was delighted to have the opportunity of doing so. He hoped he should long continue a junior Member of Council, in order to have the pleasure of seconding votes of thanks to the President in the future.

The vote of thanks was carried with applause.

The PRESIDENT believed it was an American ambassador who once, when speaking at the Mansion House, said that the man who made no mistake never made anything. He was not labouring under any illusion that he was himself infallible: for indeed he trusted that as long as he lived and worked he might be

always his own severest critic. The man who was satisfied with his work, apart from the commercial inducements which might prejudice his judgment in some cases, was to be pitied. He quite agreed with Mr. Pirrie that no one who was worthy of being called an engineer ever finished a piece of work without seeing where he might have done it better. This was particularly true of the address he had just delivered. Having many other matters pressing on his mind, he did not find it quite easy to produce the number of presidential addresses which the present year demanded of him. While he esteemed it a great honour to be asked to occupy the Presidency of this Institution, he could assure the members that he found the office no sinecure. The new year in the new house he hoped might in some respects witness new methods of usefulness; and to these matters the Council were giving their most earnest consideration. They wanted to make the fullest use possible of their increased opportunities for developing the work of the Institution; and signal as it already was, the success of the Institution, if it was to be sustained, must be sustained in a great measure, perhaps in the greatest measure, by the efforts of the members. Scattered about the country, they had an opportunity to increase interest in the Institution; and of course they would themselves reap a share of the benefits thence arising. At any rate he was sure all the members would desire that the Institution should continue to flourish, and they would all be more and more proud of belonging to it. Mr. Pirrie in his concluding words had betrayed his nationality by expressing the hope that he should long remain a junior Member of the Council. For many years it had been his own misfortune to be thought too young for the posts he had occupied; but year by year that argument was ceasing to have much force. He trusted he should live to see Mr. Pirrie high up in the Council of the Institution, and that the time would come when, if he was now the first Irishman to be a Member of the Council, he would also be the first Irishman to be President of the Institution. He thanked the members most heartily for their kind reception of him on all occasions, and for their particularly kind reception of his address.

(The President.)

There was one announcement which he had not made before, because it did not grow out of the formal business. Since the Institution last met, their friend and Past-President, Mr. Jeremiah Head, had been taken from them : a man who in his time had done a great work for the Institution, and had devoted himself to its interests, and whose death had come all too soon. Having made frequent business visits to America and other countries during his latter years, Mr. Head had never returned without bringing back with him much interesting and practical information, as the result of his own personal observation, which he had most freely communicated to the engineering profession at the meetings of this and other Institutions. In recent years in particular he had drawn attention to the great and rapid adoption in the United States of electric power for the performance of mechanical engineering work, even of the heaviest description. This was one of the salient points to which a portion of the address he had just delivered had been devoted. It was well therefore to bear in mind the memory of their departed friends, and of all they had done for those who were remaining to reap the benefit of their exertions.

EVAPORATIVE CONDENSERS.

By Mr. HARRY G. V. OLDHAM, of London,
Associate Member.

Advantages of Evaporative Condenser.—The Evaporative Condenser which is now being rapidly developed has forced itself upon the users of large quantities of steam, and of necessity finds a place in the equipment of large generating stations for supplying light and power by electricity. Jet and surface condensers are in many cases prohibited by reason of the large quantities of cooling water consumed, and by the waste of the latter unless some method of cooling it is adopted; this again entails the apportioning of large ground space for the necessary cooling ponds and apparatus. Sometimes large steam engines have thus been compelled to work without a condenser; inability to reduce the back pressure on the piston is then a drawback. When an evaporative condenser is employed, the actual amount of condensing water used may be from 25 to 30 per cent. less than the amount of feed-water used when the engines were non-condensing, and about one-fortieth of the water supply when surface-condensing. Throughout this paper 20 lbs. of steam per hour is taken as the amount required to develop one horse-power.

Principle of Evaporative Condenser.—The general principle of the condenser is simple, and consists in the use of a number of copper, brass, wrought or cast-iron tubes, arranged horizontally or vertically according to the kind of condenser employed. The tubes are connected with chambers at each end; through the inside of the tubes the exhaust steam is passed, and water is allowed to flow over their external surfaces. Part of the water on the external surface is being evaporated, and carries away with it the heat taken from the steam. A more rapid and better result is obtained, if a fan is used to remove the hot damp air.

It is well known that, at such pressures as have to be dealt with in the condenser, the thermal units in 1 lb. of steam are about 1,000 more than in 1 lb. of water at the same temperature. Before any condensation takes place therefore, it is necessary to withdraw this number of thermal units from the steam. The latter not only heats the circulating water as in a surface condenser, but evaporates a considerable portion of it. Each 1 lb. evaporated from the surface of the tubes takes with it about 1,000 thermal units; and thus for each 1 lb. of steam condensed 1 lb. of cooling water should be the utmost quantity even theoretically required. It has in fact been shown by experiment that only two-thirds of this is practically required, a large amount of heat being dissipated by radiation, conduction, &c.

Distribution of Steam inside Tubes.—The action that takes place inside the tubes is as follows. The exhaust steam which is in contact with the internal surface of the tubes condenses first, causing a momentary vacuum; fresh steam fills its place and is condensed, and so on till the whole is treated. There is a tendency, when the tubes are of a large diameter and the steam passes through without taking a circuitous course, for a central core of steam to pass through without being condensed; it is therefore desirable to stir up the steam, so that the condensation may be more rapid and effective. Internal steam distribution has been provided for by Mr. Row, by whom the indented tube shown in Figs. 7 and 8, Plate 41, is used in exhaust-steam heaters &c. with interesting results. Here the exhaust steam in its passage through the tube impinges against one indented surface and is thrown off against another, being thus split up so as to bring all parts of the steam into contact with the tube. In providing for internal steam distribution, Mr. Wright places a tube of smaller diameter inside the larger upon which the film of water flows. This does not break up the steam, but eliminates the uncondensed core, and utilizes the largest surface of the tube area. Messrs. John Fraser and Son have devised a series of internal spiral distributors, Fig. 15, Plate 42, which are so thin that they do not in any way contract the area through the

tubes or impede the flow of exhaust steam. The latter on entering the tubes is split into two portions by the spiral partition, which gives the steam a spin as it passes through. The internal distribution in the Ledward tube is shown in Figs. 18 and 19, Plate 42. The exhaust steam follows the transverse corrugations, and is drawn to the surface where they are largest. Though space for a central core exists, it is maintained that the steam is sufficiently disturbed in the tube, from the fact of its having to pass in and out of the corrugations. These act as a trap to any solid matter, and particularly to oil which may be carried over with the exhaust steam.

Distribution of Water over Tubes.—In a great measure the success of an evaporative condenser is due to a proper distribution of the cooling water over the external surface of the tubes. In a vertical-tube condenser the water is delivered into a top receiving tank, through which the tubes pass, the holes in the tank having a larger diameter than the tubes. This leaves an annular space, through which the circulating water flows on its way down each tube into a receiving tank below. In a horizontal-tube condenser the distribution is somewhat different. At the extremities of the rows of tubes and at right angles to them is placed a rectangular tank, into which the circulating water is pumped. Galvanized-iron pipes are led horizontally from the tank, and are carried above each top tube in the condenser. Each pipe is perforated, so as to allow the water to fall over the whole length of each uppermost tube. The water passes round the circumference of the top tube, is collected underneath and distributed over the next below, and so on until it has passed round each tube, and is finally collected in a receiving tank at bottom. The most important methods employed are those of Theisen, Wright, Fraser, and Ledward, Plates 41 and 42.

Theisen uses vertical brass tubes of about 2 inches diameter, shown in Fig. 1, Plate 41. Round each of these is wound in the form of a helix or screw thread a No. 9 gauge (0·150 inch thick) galvanized steel wire, with the view of causing the water to follow this course round and round the tube until it reaches the bottom.

Wright places round the vertical brass tube brass-plated wire in the form of ordinary galvanized wire-netting, Fig. 2, Plate 41. This appears to give a satisfactory distribution of the water. Later designs have spaces left between the lengths of netting, which allow of the latter being moved up and down for cleaning the tubes and removing scale, as shown in Fig. 2.

In the Fraser vertical condenser perforated conical brass cups are placed round the brass tube, as shown in Figs. 3 and 4, Plate 41, about 12 inches apart, connected by a light rod on each side. It was found by experiment that the rupture of the film of water took place after falling about 12 inches; and the action of these cups is to collect the water at distances of about 12 inches, so that there is a steady film of water continually passing down the tubes. A small annular space is left between the lower edge of the cup and the tube, for allowing the water to pass through. Several slots are made in the side of the cups, through which the water can still flow, even should the annular space become obstructed by sediment or dirt. The cups also act as tube scrapers by being moved up and down by hand.

In Figs. 5 and 6, Plate 41, is shown a brass tube which is now being introduced for evaporative condensers of the vertical kind. The tube has longitudinal corrugations drawn into it for the greater part of its length, giving 25 to 30 per cent. more surface than the plain tube. The ends are left plain for about 3 inches, to allow for jointing and expansion. Figs. 7 and 8 show the Row indented tube, as applied to evaporative condensers.

With the Fraser horizontal tube, Figs. 9 to 12, Plate 42, water is taken from a rectangular tank, and passes along a horizontal perforated or slotted galvanized-iron pipe immediately above the condenser tube. For further distribution on the lower tubes, a strip of galvanized iron extending the whole length is fixed on the under side of each tube by means of iron straps or brass spring-clips, Fig. 14. When fans are used with this kind of condenser, a curved trough is fixed under the lowest tube of each row, turning the water off into side tanks; this prevents it from dropping upon the fan blades, and also prevents the disturbance of the water on the face of the tubes.

In the Ledward condenser the water distribution is carried out as shown in Figs. 16 and 17, Plate 42. A main pipe is laid at right angles to the nest of tubes, and is supplied with water from the circulating pump; from the main are led branches, one over each row. The branch pipes are about 2 inches diameter, and have $\frac{3}{8}$-inch holes drilled along their upper side, immediately over which are fitted deflecting caps, extending the whole length of the distributing pipes and resting upon them. The water is forced into the distributing pipes and out through the $\frac{3}{8}$-inch holes, where it impinges against the deflecting caps, which spread it over the intermediate spaces. It falls in a film over the uppermost tubes, where it is caught by the uppermost ribs; it then flows round over the surface of the tubes, and is collected again by the lower ribs, ready for distribution upon the remaining tubes. Fig. 13 shows a wrought-iron tube without corrugations.

Other methods of distributing the water over horizontal tubes are shown in Plate 43. Figs. 20 and 21 show a wooden trough, into which water is pumped. The inlet pipe should be laid in the bottom of the trough for the whole length, with holes on the under side, to prevent any commotion of the water, and insure an even flow over the taper sides. The trough should be arranged perfectly level, with plain sides A or with holes B or notches C at intervals as shown, one trough delivering over two tubes. Figs. 22 and 23 are enlarged views of the cast-iron tubes T. Figs. 24 and 25 show a V trough with notches at intervals, through which water passes. A similar trough, but perforated at the bottom, is shown in Figs. 26 and 27.

Jointing of Tubes, and Water Seal.—It is highly important that all joints should be substantially made and perfectly air-tight. In some vertical condensers both the upper and the lower ends of the tubes are connected to the steam-chambers by triangular jointing-plates, Figs. 28 and 29, Plate 44. Expansion is provided for by the tubes sliding through the packings. The plates are generally made to allow three tubes to pass through. The holes are countersunk on the under side, the steam chambers being correspondingly

countersunk on the upper side, and a rubber ring is squeezed between the conical surfaces by a substantial bolt in the centre of the triangular plate, Fig. 29. A later arrangement does away entirely with the top triangular jointing-plate, the tubes being fixed at the top by having their upper ends expanded directly into the top steam-chamber, Fig. 28. For removing or replacing a leaky tube, bolted covers are provided on both top and bottom steam-chambers; and the cover immediately above the leaky tube is taken off for allowing the tube to be withdrawn. In designing therefore it should not be forgotten to allow sufficient head room for this purpose. The lower jointing-plates and steam-chamber have a rib about $\frac{1}{2}$ inch high all round the edge, as shown in Fig. 28; by this means the lower ends of the tubes are always covered with water, and any small leakages are prevented from destroying the vacuum. The upper ends of the tubes are covered by the head of water always in the top water-tank.

In the horizontal condensers, both ends of the tubes are fixed by being expanded into a substantial tube-plate. Should leaks occur at the tube ends, the covers may be taken off, and the leak made good with very little trouble. The inlet and outlet connections for the nest of tubes are both made in the steam chamber at one end, which is a fixture, while the steam chamber at the other end is free to expand upon suitable rollers arranged beneath it. In the Fraser condenser the ends of the tubes before they reach the tube plate pass through a rectangular box, Figs. 30, 31, and 32, which is open at the top and closed at the bottom, and is bolted against the tube plate with a water-tight joint. It is kept full of water by means of a small supply-pipe, Fig. 30, led from the distributing tank.

Description of various arrangements of Condensers.—In Figs. 33 and 34, Plate 45, are shown two views of a Ledward cast-iron condenser, suitable for about 150 H.P. It consists of a number of transversely corrugated horizontal tubes, connected together at the ends by U tubes and in the centre by ordinary flanges. The exhaust steam enters each vertical section through a branch from the main pipe A; it passes through the tubes in the direction of the arrows

to the air-pump suction B, and thence in a condensed form through the air pump. The circulating water is pumped up through the pipe C into the horizontal pipe D at top, from which branches are led over each section of condenser tubes; the water overflows, and is circulated over the tubes as before described. It is then collected in the lower tank, where it finds an outlet through the pipe E to the suction of the circulating pump F, and is used again. The head of water in the cast-iron collecting tank is maintained at a constant level by means of a ball cock. The air and circulating pumps are here shown directly under the condenser.

In Figs. 35 and 36, Plate 46, is shown another arrangement of a Ledward condenser, which is working at the Chapel Street station of the Kensington and Knightsbridge Electric Light Co., London. It consists of two bays of the corrugated tubes. The exhaust main runs between the bays, and has branches to right and left, connecting with each section. The condensed steam passes into the return pipe at bottom, and is collected in a drain box, and thence flows through a pipe leading from the lower part of the box to the hot well. From the upper part of the drain box a pipe is carried up into a common main leading to the air-pump suction. Each bay is supplied with a main circulating-water delivery, connected directly with the circulating pump; distributing pipes from the main are led over each section. This condenser is at present working with engines using a total of 20,000 lbs. of steam per hour, and maintains a vacuum of 23 to 27 inches of mercury, depending on the temperature of the circulating water. The quantity of water circulated is from 20,000 to 30,000 gallons per hour. The tubes, shown in Fig. 18, Plate 42, are in 5 feet lengths and 5 inches internal diameter. There are two lengths of tube, together providing without the bends a total length of 10 feet actual cooling surface. The tubes are jointed together with asbestos sheet, soaked in boiled oil, which appears to make a suitable joint for this class of work. They can be easily removed for repair. The conductivity through them is slow; therefore a considerable cooling surface is necessary. The condenser may stand as shown in Plate 45, upon girders with a cast or wrought-iron tank below, generally about 2 feet deep; or sometimes

over a brick sump finished inside with cement, as in Plate 46. Fans are not employed; the evaporated water is carried away by the current of air blowing round the condenser. The amount of radiating surface allowed is about 1 square foot for every $1\frac{1}{4}$ lb. of steam to be condensed per hour; and each tube 5 feet long condenses about 40 lbs. of steam per hour or 2 H.P.; or 8 lbs. of steam is condensed per hour per foot run of tube. The ground or roof space required varies; but the maximum may be taken at about 36 square feet per 40 H.P., that is about 0·9 square foot per H.P. A condenser—

for	100 H.P.	would require about	90 sq. ft. ground space.
„	500 „	„ „ „	450 „ „ „ „
„	1000 „	„ „ „	900 „ „ „ „

Some interesting results were obtained by experiments with a condenser of this kind connected with two Willans engines of 350 H.P. The condenser was situated about 140 feet from the engines, and the total distance travelled by the exhaust steam from the engines to the air pump was 350 feet, causing a difference of about $\frac{3}{8}$ inch in the mercury gauge between these two points. It was also found that the engines could run and be maintained at full vacuum with a load of 100 H.P. without the use of any cooling water.

A similar condenser, Figs. 37 and 38, Plate 47, is in use with cast-iron tubes, which are plain with the exception of the thin fin cast along the under side to collect the water for distribution upon the lower tubes. The circulation of the steam is exactly the same as in the preceding example. More sections may easily be added to this and other kinds of horizontal condensers. The distribution of water over the tubes may be carried out by any of the methods shown in Plates 42 or 43. At a colliery some time ago a condenser of this kind was erected above the ground level, for condensing the steam from the engines, one of which works in the mine about 100 feet below the level of the condenser; and this arrangement is still working satisfactorily.

A Fraser condenser with horizontal wrought-iron tubes, for dealing with 40,000 lbs. of steam per hour, Figs. 39 and 40, Plate 48, has been erected at the generating station of the Waterloo and City

Electric Railway. It is arranged in two bays, right and left of the main exhaust-pipe; and in each bay two sets of sections are arranged vertically one above the other; each bay is complete with distributing tanks and pipes. From the vertical continuation B of the main exhaust-pipe two inlet branches V_1 and V_2 are connected through valves to each set of the lower and upper sections, so that one half of the condenser may be shut off if required. At the top of the vertical continuation B is an automatic relief-valve, which may be kept open for any length of time by means of the lever and cord, in order to allow of an examination being made without interfering with the running of the engine non-condensing. The inlet branches V_1 and V_2 pass between the bays, and pipes are led from them to each section. The steam, on entering at the top of any section of the condenser through the inlet pipe, passes first through ten tubes, arranged in two vertical rows alongside each other, with five in each row; it next returns through a lower double row comprising eight tubes, goes forward again through the same number at a yet lower level, and finally passes to the air pump through the six lowest tubes, Fig. 39. The tubes are 3 inches diameter and about 18 feet long, and are of galvanized wrought-iron. The condensed-water outlet pipes JJ are arranged in a similar manner to the exhaust-steam inlet pipes BB. The inlet and outlet pipes are so arranged and jointed that any single one can be removed with only a few minutes' stoppage, or the whole section to which it is connected may be completely shut off. The water-distributing tanks RR are above the branch inlet steam-pipes V_1 and V_2, with perforated distributing pipes leading from them to immediately above each row of condenser tubes; a separate pipe from the circulating pump is led into each tank. The distributing pipes from the circulating pump have valves fitted to them, so that the circulating water may be shut off from either distributing tank. Underneath the whole condenser are water-collecting tanks and four fans. The latter are driven from the underside by a continuous rope working from a pulley on the shaft of an electric motor. Toothed bevel gearing has been tried for this purpose, but has not proved satisfactory with the speeds at which the motor shaft is run. The

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fans are $5\frac{1}{2}$ feet diameter, and run at about 300 revolutions per minute; the cooling water is prevented from falling on their blades by the U troughs shown. The condenser is situated about 100 to 120 feet from the engines and about 150 feet from the air pump, measured along the lines of piping. The ground space occupied by the condenser is 1 square foot per 5 H.P. The automatic relief-valve shown in Fig. 61, Plate 56, consists of a cast-iron body, with a cast-iron valve having a fibre seating. The chamber above the valve seat is of sufficient depth to prevent the steam from spreading when issuing from the valve; and also to hold a sufficient quantity of water for effectually sealing the valve when closed, and preventing any air leakage inwards. Should any loss of water occur through leakage, a small supply pipe may be led into this chamber. Fig. 41, Plate 49, is a photograph of a Fraser horizontal condenser at Blackpool, showing water circulating over the tubes.

The Fraser vertical brass-tube rectangular condenser is shown in Figs. 42 and 43, Plate 50. Four pairs of rectangular chambers are connected by vertical brass tubes about $1\frac{1}{4}$ inch diameter, jointed in the method before described. Around the four top steam-chambers are tanks, through which the tubes pass, leaving a small annular space; through this the cooling water flows down the condensing tubes to the water tanks below. On each of the tubes is placed a set of the brass cups shown in Fig. 3, Plate 41. The steam enters at the top through the main exhaust-pipe, from which are taken branches to the four upper steam-chambers through the controlling valves shown. Outlet pipes with controlling valves are taken from each of the lower chambers into the main outlet pipe, and then direct to the air pump. The long upright vessel to the left in Fig. 42 is an air cooler, and simply deals with the hot air from the top steam-chambers. This apparatus was designed to condense for about 600 H.P.

The Fraser circular condenser, Fig. 44, Plate 51, has concentric rings of tubes jointed to top and bottom annular boxes, with a set of cups on each tube. The exhaust steam enters by two inlets at the bottom box, and is made to pass up and down the tubes by means of partition plates, and finally to the hot well through the pipes B.

The air pump is connected to draw from the top box; and the other connections are also shown. Inside each tube is a spiral distributor, Fig. 15, Plate 42. The fan at bottom is 5 feet diameter, running at 400 revolutions per minute.

The Theisen circular evaporative condenser, which appears to have been the pioneer of the vertical brass-tube condensers working with fans in this country, is shown in Fig. 45, Plate 51. It consists of two annular steam-chambers connected by vertical brass tubes, which are arranged in radial rows of three, and are lapped round helically with wires, Fig. 1, Plate 41. Immediately below the top steam-chamber is a water-tank, through which the tubes pass; and another water-tank is fitted at bottom to collect the cooling water. The bottom water-tank was originally arranged below the bottom steam-chamber, and the tubes in that case were not submerged; but in later designs the bottoms of the tubes are completely covered, as shown in Fig. 45. The steam is taken in at the bottom, and after passing through the condenser tubes is taken out again at the bottom directly to the hot well. The pipe to the air-pump is taken from the top of the condenser, and the air pump then deals with air only, which is cooled before reaching the air pump. The fan or air propeller discharges air at right angles to the tubes. By the use of the fan it is said that the condensation of steam is increased 50 per cent. The fan is run at a low speed, about 80 revolutions per minute, because a greater speed has been found to disturb the cooling water on the surface of the tubes.

In connection with these condensers a supplementary condenser or cooler, Fig. 46, Plate 52, is sometimes used. It consists of a vertical cast-iron or steel vessel, filled with brass tubes. Any uncondensed steam or admixed air from the main condenser passes in at the top and down inside the tubes, as in an ordinary surface-condenser. Fresh cold water, which is used to make up the loss by evaporation in the main condenser, is passed through the cooler, and then delivered with the other circulating water into the top water-tank over the tubes. The final temperature of the air from the condenser is thus reduced lower than it otherwise would have been. It will be seen that in the main condenser the hot exhaust steam is always

in contact with the hottest circulating water, and that in the cooler the hot air passing to the air pump is exposed last to the coldest temperature of the water passing through the cooler. The steam as it is condensed in the main condenser naturally falls, and the circulating water starting at the top gravitates to the bottom, where its temperature occasionally rises so high as to cause a loss of vacuum. The following are the temperatures of the steam at various pressures below the atmosphere :—

Vacuum in inches of Mercury .	0	11	18	22½	25	27½	28½	29	29½
Temperature of Steam . Fahr.	212°	190°	170°	150°	135°	112°	92°	72°	52°

A Theisen circular condenser without a fan is shown in Fig. 47, Plate 52, in which an upward current of air is induced by means of the iron chimney at the top of the casing surrounding the condenser. These condensers are also made in the rectangular form. The tubes are lapped with special fabric. In compiling Table 1 Messrs. D. Stewart and Co. of Glasgow, makers of the Theisen condenser, have taken 30 lbs. of steam per hour per I.H.P.

TABLE 1.—*Theisen Evaporative Condenser. Plate* 52.

Power of Engine .	H.P.	75	100	150	200	300	400	500
Steam condensed per hour . .	lbs.	2,250	3,000	4,500	6,000	9,000	12,000	15,000
Space required, square feet		40	40	56	72	72	110	110
Height	feet	10	11	12	12	12	13	14
Condensing water per hour . .	gallons	330	450	675	900	1,350	1,800	2,250
Total power required to work condenser	H.P.	2	3	4	5	6	8	10

A minimum of one square foot of tube surface per 8 lbs. of steam condensed per hour is generally provided. In the supplementary cooler, Fig. 46, Plate 52, it is usual to allow one square foot of

surface for 80 lbs. of steam per hour. A set of Theisen condensers at present working deals with 3,000 H.P.; it consists of four circular condensers. There are altogether eleven separate engines with thirty-one cylinders; one engine of 200 I.H.P. is 260 feet from the condenser and 130 feet from the air pump. A 12-inch centrifugal pump supplies the circulating water. A 16-H.P. engine drives this pump and fans, and an additional 15 H.P. is required for the air pump, which is 16 inches × 16 inches and is driven at 100 revolutions per minute; the 31 H.P. therefore is just over 1 per cent. of the total engine power.

The Wright condenser is vertical, and resembles those already described, the chief difference being in the method of distributing the cooling water over the surface of the tubes. In Plate 53 are shown two views of a Wright condenser suitable for about 500 H.P. It consists of four upper and four lower rectangular steam-chambers; the two chambers of each pair, forming one section of the condenser, are connected together by sixty brass tubes about 15 feet long by 2 inches diameter. Around these tubes is placed the distributing netting, Fig. 2, Plate 41. One such section contains about 500 square feet of cooling surface; and seven sections are allowed for about 1,000 H.P. The main exhaust-pipe rises vertically, with a relief valve on the top; just below the valve a swan-neck bend is led into the main inlet pipe A, from which are led four branches B, one to each upper steam-chamber. The steam passes into the condensing tubes, and may be made to pass up and down them again by the interposition of partition plates, till it reaches the lower steam-chamber and the condensed main C at the opposite lower corner; a connection is made from each steam-chamber to the condensed main. In the partitions are made holes for allowing the condensed steam to drain to the outlet, while the uncondensed steam passes up again through the tubes. The condensed steam may be taken direct to the air pump, or may pass through the cooler shown. Connection is also made to the cooler from the top of the condenser, in order to take away the hot air, thus reducing the final temperature in the condenser, and so preventing re-evaporation. For the water circulation a supply tank is fixed in any convenient position, a

connection is made from it to the circulating pump, and a delivery pipe is carried up to the level of the top water-distributing tanks, whence branches S are led over into each tank; the water passing through annular spaces in the tank bottom flows down the tubes and wire netting. At the bottom it is collected in the lower receiving tanks, and flows through branches into a discharge main D leading to the circulating-water supply-tank. The fan of 5 feet diameter may be placed directly under the condenser; but in a condenser now being erected at Hastings it is placed at the top, and the shaft passing down through the condenser is driven by an electric motor.

Leading Water over Tubes.—With the vertical condenser some difficulty has been experienced in getting the water to start evenly down the tubes. An early method was to countersink the bottom of the water tank, Fig. 50, Plate 54; but it was found that the cup formed by the countersink soon became filled with solid matter which came over with the circulating water, so that the water could not get through at all. The countersink was then reversed, Fig. 51, which was a marked improvement. In the Wright condenser the annular outlet for the water is raised above the bottom of the tank by means of a lip, shown in Fig. 52, thus keeping back any obstruction in the bottom of the tank. A later arrangement is shown in Fig. 53, in which a brass bush is driven into the bottom of a cast-iron distributing-tank. But the tubes cannot always be depended on to keep a perfectly central position in relation to the holes in the tank. To remedy this a substantial conical cup was placed immediately below the tank, Fig. 54.

An evaporative condenser with horizontal tubes, which was erected by Sir Frederick Bramwell twenty-six years ago in Belvedere Road, London, is still at work producing a satisfactory vacuum. It is illustrated in Plate 55, and consists of eight sections, each containing 32 wrought-iron tubes of 1 inch diameter internally. The sections are divided into two parts, upper and lower, each having its own water-distributing trough. The troughs are supplied with water from an overhead tank, from which are led bends delivering into

each trough. The exhaust steam enters through a pipe at the top right-hand corner, and passes into each section through flanged branches; the condensed steam is drawn off at the lower opposite corner by a similar pipe, which is connected with the air pump. A tank is fixed underneath to catch the circulating water. The ends of the tubes pass through the cast-iron tube-boxes, and each is jointed inside by means of an ordinary gland with a rubber joint and two bolts, as shown in Figs. 59 and 60, Plate 56. An enlarged view of the water-distributing trough is also shown in Figs. 57 and 58. The condensers are connected with a Watt beam-engine, indicating about 150 H.P.; the air and circulating pumps are worked from the beam.

A similar condenser by Messrs. John Kirkaldy, which is principally in use abroad, is shown in Plate 57. It consists as usual of two end boxes, into which the horizontal galvanized wrought-iron tubes are fixed by expanding their ends, Fig. 62. Opposite the end of each tube is a small gland-shaped cover in the end of the box, Fig. 63, for the purpose of facilitating the fixing of the tube end and examination of the joint. The water is distributed by means of a triangular V-shaped trough with holes drilled through the bottom. The condenser here shown is suitable for condensing 2,000 lbs. of steam per hour. Its height is 10 feet, its total length 12 feet, its width 5 feet, and it contains forty tubes. Such condensers weigh about 1 cwt. per 30 lbs. of steam condensed per hour.

The vertical cast-iron condenser shown in Plate 58 consists of two rows of vertical tubes S, connected at the top by bends, and leading from one horizontal pipe into another. A is the exhaust main, and B the air-pump suction-pipe for drawing off the condensed steam. The vertical tubes are 4 inches diameter. A cast-iron trough D is fixed across and above them, and immediately over each tube the trough is perforated with a hole, which allows the water to fall directly on the centre of the bend, whence it runs down the whole length of the tube to the cast-iron collecting tank F at bottom. The delivery pipe to and from the circulating pump is shown at E and C respectively. The whole apparatus is supported

above the tank F. The vertical tubes are about $\frac{5}{16}$ inch thick, and the larger pipes $\frac{1}{2}$ inch to $\frac{5}{8}$ inch. In connection with this condenser some valuable experiments were made and recorded by Mr. Michael Longridge in 1892.* Table 2, and the diagram,

TABLE 2.—*Condenser with Vertical Cast-Iron Tubes. Plate* 58.

1	Date	1892	Sep. 12	Sep. 13
2	Weather		Wet	Fine
3	Barometer	ins.	29·8	29·5
4	Temperature of air	Fahr.	?	60°
5	External surface of condenser . .	sq. ft.	272	272
6	Duration of trial	minutes	99	115
7	Weight of steam condensed during trial .	lbs.	800	800
8	Boiler pressure per square inch . .	lbs.	60	60
9	Weight of water in circulation, about .	lbs.	1,830	1,830
10	Weight of fresh water added during trial	lbs.	600	640
11	Weight of water lifted by circulating pump	lbs.	11,200	?
12	Vacuum in condenser, per mercury gauge	ins.	23·36	24·1
13	Initial temperature of circulating water in distributing trough D . . .	Fahr.	117·5°	113·9°
14	Final temperature of circulating water falling into collecting tank F . .	Fahr.	128·4°	125°
15	Temperature of supplementary fresh water from town main	Fahr.	58°	58°
16	Temperature of water in hot well . .	Fahr.	136·5°	131°
17	Weight of steam condensed per minute .	lbs	8·08	6·95
18	Weight of circulating water delivered into distributing trough D per minute .	lbs.	113·1	?
19	Weight of supplementary fresh water poured into collecting tank F per minute	lbs.	6·06	5·57
20	External surface of condenser per lb. of steam condensed per minute	sq. ft.	33·7	39·1
21	Volume displaced by air-pump bucket per minute (up strokes only), per lb. of steam condensed per minute	cub. ft.	2·5	2·9
22	Volume displaced by bucket of circulating pump per minute (up strokes only), per lb. of steam condensed per minute	cub. ft.	0·31	0·36

Fig. 66, Plate 58, are taken from his report, showing the temperature of the circulating water and of the air-pump discharge, with the weight of circulating water delivered over the tubes. This condenser was made by Messrs. Cooper and Grieg, Dundee. The conditions were unfavourable, owing to damp weather and the

* The Engine, Boiler, and Employers' Liability Insurance Co., Chief Engineer's Report for 1892.

position of the overflow tanks. The tubes were coated with a thin scale outside, but were clean inside. It will be seen in line 7 of the Table that 800 lbs. of steam were condensed during the trial, and also that the make-up water in line 10 was 600 lbs. during the same time. Thus $\frac{3}{4}$ lb. of water was evaporated per lb. of steam condensed.

In a paper read by Mr. Row,* some interesting experiments were described, showing the value of air currents directed upon vertical condensing tubes with water passing over them. Figs. 67 and 68, Plate 59, represent the experimental apparatus used; and Table 3 shows the results of the tests. The plain-tube test was conducted with a tube shown in Fig. 68 before being indented. The steam, was admitted into the tube at the valve A, and the condensed water

TABLE 3.—*Tests with Plain and Indented Tube, and with Air Current. Plate* 59.

Description of Test.	No. 1. Plain Tube and Condensing Water only.	No. 2. Indented Tube and Condensing Water only.	No. 3. Indented Tube and Condensing Water, assisted with Air Current.
Time, one hour — commencement . .	10.45	12.0	3.0
Time, one hour — finish	11.45	1.0	4.0
Temperature of atmosphere . . .	65° F.	70° F.	64° F.
Temperature of condensing water in pan G and bucket G′ . . .	133° F.	120° F.	115° F.
Temperature of condensed water at D	154° F.	155° F.	153° F.
Weight of condensing water evaporated . . . . . . lbs.	10·62	27·00	50·0
Weight of steam condensed . lbs.	20·62	39·69	63·4
Evaporation ÷ Condensation, ratio	0·51	0·68	0·78
Vacuum per square inch . . lbs.	10	10	10

* Manchester Association of Engineers, Transactions 1897, page 57.

dropping into the receiver B was drawn off at stated periods from the cock D. The vacuum was induced by the ejector C. The cooling water was raised by pumping, and allowed to trickle in a thin film from the pan F at top; the water not evaporated fell into the pan G and bucket G′ and was re-pumped. The test shown in Fig. 67 was conducted in a precisely similar way, with the addition of the casing H, through which an air current was induced by an ejector in the branch J. The plain tube in test 1 was 16 feet long, $1\frac{1}{2}$ inch internal diameter, and No. 16 wire-gauge thick (0·065 inch). This was afterwards indented for tests 2 and 3 when it measured 14 feet $5\frac{3}{4}$ inches long. The total condensing surface exposed to the atmosphere was 8 square feet, including the surface in the pan G and receiver B. On the basis of test 3 with air current, deducting 25 per cent. from the result obtained under experiment and taking the condensing efficiency of indented copper as equal to 6 lbs. of steam per hour per square foot of surface, it is possible for an evaporative condenser for 200 H.P., allowing 20 lbs. of steam per H.P., to be enclosed in a casing $3\frac{1}{2}$ feet square, standing 12 feet high. In these single-tube experiments, the air current in Fig. 67 was induced to pass the surface of the tube in a way that is not obtained in present practice. The fan, if placed at right angles to the tubes at the bottom, as shown at B in Fig. 78, Plate 61, would force the air against the opposite casing, almost entirely destroying the nature of the current; after which it would have to find its way at any angle past the tubes. It is doubtful whether a condenser of the size given above would be capable of dealing with 200 H.P. Two views of a Row evaporative condenser with fan are shown in Plate 60.

Design, Arrangement, and Efficiency of Fans, as applied to Evaporative Condensers.—It has been shown by experiment that, by the use of a current of air passing over the surface of a tube upon which water is running, the condensing efficiency can be increased by nearly 70 per cent. Taking full advantage of this 70 per cent. as equivalent to 41 per cent. reduction in surface, an

evaporative condenser with vertical brass tubes should not require more surface than an ordinary surface-condenser, that is, about 2 square feet per I.H.P., though satisfactory results have not yet been obtained from this proportion. Various arrangements of fans are shown in Plate 61. Fig. 71 represents a tube exposed to the atmosphere, with a small propelling fan at the lower end; the tube might be enclosed, as in Figs. 72 or 73, without great loss of efficiency. These three arrangements would suggest that probably a freezing action would take place near the tube, due to the rapid evaporation of water caused by the air current. Fig. 74 shows a propelling fan working in the centre of a circular condenser with concentric rings of tubes. The fan may be arranged to exhaust the air from the top of the condenser, as in Fig. 75; but such an arrangement would have little advantage, if any, over the propelling method shown in Fig. 74. A propelling fan fixed directly under rectangular boxes, as shown in Fig. 76, is not so good as the same fan placed as in Fig. 74. A still inferior method is that shown in Fig. 77, in which the fan is arranged to propel the air horizontally below rectangular boxes. The propelling fan in Fig. 78 at B is also inefficient, while the design at A is not to be commended at all. The kind of condenser in most instances governs the arrangement of the fan. The efficiency of the fan itself is not considered here so much as its steam-condensing value. The examples given in Figs. 71, 72, and 73, are merely theoretical. The various arrangements shown in Figs. 74 to 78 are working in one or other of nearly all vertical evaporative condensers, and the efficiency of the apparatus is to a certain extent increased thereby in all. It is not advisable to use fans at all in horizontal condensers, and these should really be designed with sufficient surface to do without them. In a horizontal wrought-iron-tube condenser each square foot of surface should condense from 2 to 4 lbs. of steam per hour: that is, the condenser should have about 8 square feet per I.H.P. The value of a fan in increasing the hourly condensation under existing circumstances when working with vertical condensers cannot be taken at more than 20 per cent.; and this amount is often reduced to 10 per cent.

or 5 per cent., or even lower. Where condensers are not designed to take the maximum load, fans are sometimes used to carry the engines over the maximum load. The style of fan that appears to find most favour for this class of work is one with blades such as could be laid on the surface of a cone, their backs being radially straight. Transversely the faces delivering the air are concave, with convex backs. The blades are set at an angle in the usual manner. Water should not be allowed to fall on the fan blades. The power required to drive the fans varies from 1 to 2 per cent. of the total engine-power, or sometimes more.

Conditions governing Design, Arrangement, and Maintenance of Evaporative Condensers.—It is important that ample means should be allowed for cleaning, especially as regards the outside surface of the tubes. One square foot of tube surface will evaporate half a gallon of water per hour: so that, if the water were only moderately hard, the amount of deposit in a year would be considerable. The circulating water itself should be kept clean. One method of removing hard scale from the tubes resembles that adopted in feed-water heaters: namely to stop the water in circulation, and to pass steam into the condenser, when the difference of expansion between the tube and the scale causes the latter to crack; it can then, as a rule, be easily removed by hand. The exhaust pipe may enter at either the top or the bottom of the condenser. It is generally made of mild steel plate $\frac{3}{16}$ to $\frac{1}{4}$ inch thick, with substantial faced flanges riveted to each end; and pipes 18 inches to 24 inches diameter are often erected in complete lengths 40 to 50 feet long. They should if possible have a fall towards the condenser; but if circumstances do not permit of this, they can be so arranged as to drain back into a chamber at the lowest point in the run, from which a pipe is led to the air pump. The outlet pipe from the bottom of the condenser is led with a fall direct to the air pump. But where the condenser is about 29 or 30 feet above the hot well, the pipe direct to the air pump may be dispensed with, and the condensed steam may drain through a pipe directly into the hot well; the air pump then deals only with the air from the top of

the condenser, from which a much smaller pipe is led to the air pump. Between the condenser and the air pump is fixed a cooler, into which a spray of water is admitted as in an ordinary jet condenser, thus reducing the final temperature of the air.

Jointing and Testing.—All joints should be machined, and made even more carefully than steam joints. They may be made with rubber insertion, or asbestos, or asbestos soaked in boiled oil. When the tubes and condenser are erected, the whole should be tested under water pressure ; and the pressure from a water main is usually sufficient for this purpose. On the occasion of starting a certain condenser, it was found that the vacuum could not be maintained. Examination was made of all the joints, and a few noticeable leaks were stopped; but still it was far from being tight, and continued to give trouble. At last it was decided to test the whole apparatus under water pressure, when the leaks were soon detected and made good, with the result that the required vacuum was obtained. In another instance where air leakage caused trouble, the feed-pumps were abnormally large for the boilers they were feeding, and pumped a considerable amount of air along with the water. It is desirable to place the condenser as near the engine as possible, in order to save cost of pipes, bends, &c., and also to reduce the risk of leakage. Condensers are working satisfactorily at a distance from the engines of 100 to 120 feet, and in some instances even more. The horizontal condensers should be exposed as much as possible; the best place is upon the roof. Care should also be taken however, especially in the plain-tube or wrought-iron horizontal condensers, to shield the tubes from the direct action of the wind, which the author has observed to sweep a portion of the nest of tubes quite devoid of circulating water. Vertical condensers with fans and without casing are invariably placed in the open. The practice of connecting several large engines to one condenser should be discouraged; but where the engines are small, they may be connected into one exhaust main, with controlling valves to shut off each as required. Where the engine room is being extended or newly built, the roof on which the condenser is

placed should be flat and made watertight, and in one or two places sloped to a gully covered by a wire grating; connections are made from the gullies to the circulating pump. The condenser is built upon girders, and the circulating water after passing over all the tubes should be allowed a fall of 3 or 4 feet before it reaches the roof. This is an effective means of lowering the temperature of the cooling water; or a wrought or cast-iron tank of ample area and about 2 feet deep may be placed under the condenser. The arrangement of piping is shown in Plate 62. Duplicate condensers are not required, the steam being exhausted into the atmosphere while any slight repair is being made good.

Cost and Choice of Condenser.—The average cost of evaporative condensers is about 20*s.* per H.P., exclusive of the cost of air and circulating pumps and connections. Compared with jet condensers, the cost is no doubt greater; but including reservoir construction and cooling apparatus, the evaporative condenser is more economical. Some judgment must be used when selecting a condenser for any particular purpose. When ample room and good foundations are at hand, and the condenser has to be worked under rough conditions, the cast-iron condenser is more suitable and cheaper than other kinds. The horizontal condenser, fitted with wrought-iron or copper tubes, is far more efficient weight for weight, and occupies much less room than the cast-iron condenser. The scale can be more easily removed from such tubes than from cast-iron tubes. Greater success has been obtained with a distribution of water over the tubes in the horizontal condenser than in the vertical; and when space permits, the former is recommended.

The vertical brass-tube condenser with fan is adopted when space is limited. Condensers of this kind do not at present give the results which were expected, too much value having been attributed to the fans; but if ample cooling surface is allowed, the author considers that no difficulty whatever should be experienced with them.

Circulating Pumps.—Various kinds of pumps are used; that which seems to find most favour is the ordinary centrifugal pump.

Air Pumps.—It is important that an efficient air pump should be used. The size designed for an ordinary surface condenser would be generally suitable for an evaporative condenser of the same capacity. Various designs are employed, including the ordinary marine air pumps with three sets of valves, the single-valve pump on the Edwards plan, and displacement pumps similar to those used with jet condensers. In some cases three barrels are arranged alongside of one another, and are driven by a three-throw crank, coupled directly to an electric motor running from 100 to 200 revolutions per minute. The same design of pump is sometimes driven by a high-speed motor running at 1,000 to 1,200 revolutions per minute; connection is then made to the pump shaft by a worm and worm-wheel running in a bath of oil, and reducing the speed to 100 or 120 revolutions on the pump shaft. With the important subject of air pumps the author is able to deal only in a brief manner, while cooling towers and reservoirs have been purposely omitted.

Discussion.

The PRESIDENT called upon the Members to give Mr. Oldham their cordial thanks for the labour he had bestowed upon the preparation of this interesting and extended description of evaporative condensers.

Mr. OLDHAM assured the Members he fully appreciated their cordial reception of the paper. In addition to the condensing tubes described therein, he should like to draw attention to the new construction of Kynoch tube shown in Figs. 81 and 82, Plate 63, which was approximately heart-shaped in cross section, and had small

(Mr. Oldham.)

circumferential ribs cast upon it, or drawn upon it if it was made of steel, for collecting the water in between the ribs, and giving an even flow over the whole length of the tube. When the tube was designed, it was arranged to be made in steel, which would of course have to be rolled to a special section with the ribs upon it. The tube itself was rolled into the heart-shaped section, the two free ends were brought together and riveted up, with a caulking strip in between. The flanges would have to be formed on the ends of each length of tube; and from this mode of construction he feared considerable leakage would result at the flanged joints and rivets. In Figs. 81 and 82 the tube was shown as made in cast-iron, which he thought would be less likely to cause trouble than the built-up steel tube. The cooling water was collected in the longitudinal depression or recess, which ran all along the top of the tube, and from which the water flowed slowly over the tube in a thin film. This section of tube he thought would have a slight advantage over a round tube. It collected the water on the top; and if it was placed perfectly level, the water would flow over quite evenly down upon the next tube below.

Mr. Bryan Donkin, Member of Council, pointed out that the title "evaporative condensers" did not necessarily imply that it was steam which was to be condensed. There were now so many gases which could be condensed, and it seemed probable that in future years there would be so many more, that he thought it should be stated what vapour it was intended to use in the evaporative condenser. It seemed to him therefore that it might be preferable to call these evaporative condensers "air and water condensers for steam." Surface condensers of this kind seemed to be coming more and more into use; and it was therefore interesting to have the experiments which had been given in the paper, particularly those made with the induced or forced draught of the fans (pages 202–203).

From his experience of open-air condensers in towns, the surfaces of the tubes both inside and outside were everywhere largely exposed to dirty water, and the same water was often used over and over again. To this question of dirt he thought sufficient

attention had not been paid: dirt on the tubes, and dirt in the circulating water. It was preferable in his opinion to have all the tubes cylindrical, so that they could be cleaned readily, not only inside but out; and arrangements should be made for this to be done in the easiest manner. Flanges he thought were most important for making the joints, so that the whole could be taken to pieces at certain intervals when necessary, and the tubes looked through from end to end. Sometimes in London, with its dirty atmosphere, as much as half an inch thickness of dirt had been found outside the tubes, and also a considerable oily and greasy deposit inside: so that any projections or depressions on the surface of the tubes, whether inside or outside, he was afraid would be only places for accumulating the deposits of dirt. As the circulating water should touch the whole external surface of the condenser tubes, the success of any condenser was greatly dependent upon the water being kept clean, as carefully pointed out in page 204. The arrangements should be such that the water should run as nearly as possible over the whole surface; and on this account the horizontal arrangement of tubes would probably be rather better than the vertical.

As to the kind of metal to be used for the tubes, he was afraid the metal itself had but little to do with the efficiency of the condenser. The rate of transmission of heat through the metal was hardly ever of consequence, because it was chiefly the dirt outside and the dirt inside that had to be penetrated by the heat, just as in boilers and other heating apparatus. The dirt acted as a great retarder to heat transmission; and though the metal did its best when it got a chance, yet unfortunately it seldom did get one.

The joints were a vital part of the apparatus. In his opinion flanges ought always to be used, and always machined; otherwise some leakage generally took place, and the vacuum was more or less spoilt. It was easy to arrange the condenser tubes conveniently for testing under pressure, so that, by simply opening one cock and shutting another, water could be admitted inside the tubes while the engine was standing, and the tubes thus be tested daily or weekly.

(Mr. Bryan Donkin.)

Air propellers were no doubt valuable for improving the condensation; but data were wanted as to the power required to drive them. In some instances the extent of the cooling surface was given in the paper; but in several it had not been stated, and if in these it could be added it would be much appreciated. Also the actual vacuum and the height of the barometer should be given in each particular case. The weather too was an important consideration: it was desirable to know whether there was a gale of wind, or no wind at all, or a thick fog, such as often occurred in London. The experiments on the Row condenser, given in Table 3, he was afraid had been made with the tubes perfectly clean, which would not be their condition in practice. In all experiments it was desirable that the actual condition of the tube surfaces, both inside and out, should be carefully noted. A condenser in America, of which he had read, had horizontal cylindrical tubes placed in shallow troughs of water; that seemed to him to be a good arrangement. He enquired whether any applications had been made of the plan of spraying the water upon the tubes under pressure.

Mr. Michael Longridge considered the subject treated in the paper was both important and interesting. It was important because the apparatus described enabled any non-condensing engine to be converted into a condensing engine with profit, provided from 30 to 40 per cent. of the cost of coal and water for the non-condensing engine would pay maintenance and interest on the outlay for the condenser. The subject was interesting, because he was sure many engineers like himself desired to know more about it. Only ten years ago he had been asked to reduce the coal bill in a mill near Dundee, which was driven by a non-condensing engine. As there was too little water to supply a jet condenser, he had suggested an evaporative condenser. The suggestion was not entertained, because neither the mill-owner nor his friends had ever seen or heard of one. Their decision he could not say had been altogether unsatisfactory to himself; for the designing of the condenser, if it had been decided upon, would have caused him no little anxiety, owing to the want of reliable information as to the quantity of surface required and the

proper arrangement of the details. Among the figures which he had collected at the time were some relating to a condenser made of pairs of vertical cast-iron cylinders, one fixed inside the other, with an annular space between the two, in which the steam was condensed by water flowing over the external surfaces. The outer cylinders were about $3\frac{1}{2}$ feet external diameter and 12 feet high, and each pair had about 250 square feet of surface. There were sixteen pairs of cylinders, or 4,000 square feet of wetted surface, for an engine developing about 400 I.H.P., giving 10 square feet per indicated horse-power; or assuming, as in the paper, one horse-power to require 20 lbs. of steam per hour, which would probably be nearly correct in that instance, there were 30 square feet of surface per lb. of steam condensed per minute. As to the quantity of water in circulation, or the loss of water by evaporation and dispersion by the wind, he had been unable to get any information. In another instance he had been told that 5 square feet per indicated horse-power was the proper amount of surface; this was equivalent to 15 square feet per lb. of steam condensed per minute. In a third instance as much as 60 square feet of surface per lb. of steam condensed per minute had been stated to be necessary. Such was the kind of information he had been able to gather then; and he thought that even now engineers had not much that was more definite to guide them. The only published figures he had found were contained in papers by Mr. Tom Westgarth and Mr. Henry Davey: the first read in March 1894 at Middlesbrough to the Cleveland Institution of Engineers (Proceedings 1893–4, page 120); the second read before the machinery section at the engineering conference of the Institution of Civil Engineers in 1897 (Proceedings, vol. 130, page 195). Mr. Westgarth quoted the experience of Mr. Henry Cochrane at the Ormesby Iron Works, Middlesbrough, with cylindrical condensers of the kind already mentioned, as showing that 10 square feet of surface with 400 lbs. of water flowing over them per hour sufficed for one I.H.P., and that with this large supply of water the loss by evaporation was about 4 lbs. per I.H.P. per hour. Assuming the engines to have used 20 lbs. of steam per hour per I.H.P., these figures were equivalent to 30 square feet of

(Mr. Michael Longridge.)

surface per lb. of steam condensed per minute, to 20 lbs. of water passing over the tubes per lb. of steam condensed, and to a loss by evaporation of 0·2 lb. of water per lb. of steam condensed. Mr. Westgarth's own opinion (page 122) was that for a triple-expansion or other good compound engine 10 square feet of cooling surface per I.H.P. would be ample, with a moderate supply of cold water; and that the loss by evaporation would be somewhat less than the weight of steam condensed. As such an engine would use from 12 to 15 lbs. of steam per I.H.P. per hour, the above surface would be equivalent to from 50 to 40 square feet of surface per lb. of steam condensed per minute. On the other hand Mr. Davey recommended 6 square feet per lb. of steam condensed per minute, supplemented by a small surface-condenser with about one square foot of surface per lb. of steam condensed per minute; and a circulation of 20 lbs. of water per lb. of steam. These figures appeared to have been derived from Mr. Theisen, as they agreed so nearly with those given in page 196 of the paper. Here again was a great diversity of opinion resting upon only a small basis of exact observation.

In order to design an evaporative condenser with confidence of success, it was necessary to know not merely the surfaces which had been applied per indicated horse-power with more or less success, but also the surfaces which had sufficed to condense known quantities of steam with known quantities of water at known temperatures; and further to know how the surfaces, the vacuum obtained, and the losses by evaporation depended upon the capacities of the storage tank and circulating pump, and upon the temperature of the cooling water. On these points the paper gave little information. From the statement in page 192—that in the Ledward condenser described in page 191 about 1 square foot of radiating surface was allowed for every $1\frac{1}{4}$ lb. of steam to be condensed per hour, and that each tube 5 feet long condensed about 40 lbs. per hour—it could be inferred that each tube had about 32 square feet of surface; in Figs. 35 and 36, Plate 45, there were shown 360 tubes of 5 feet length; hence the condenser here shown would have about 11,520 square feet of surface, or 34·6 square feet of surface per lb. of steam condensed per minute; and it was stated that from 10 to 15 lbs. of

water were circulated per lb. of steam; but no information was given as to the duration of the full-power runs, the tank capacity, the temperature attained by the water, or the loss of water by evaporation. Again by calculation from Figs. 39 and 40, Plate 48, and from the figures given in page 193, it could be ascertained that the Fraser condenser there described had nearly 9,050 square feet of surface or nearly $13\frac{1}{2}$ square feet per lb. of steam condensed per minute, but here the evaporation was accelerated by fans; no other information was supplied. The Theisen condenser (page 196) appeared to have $7\frac{1}{2}$ square feet of surface per lb. of steam condensed per minute, being supplemented by a small surface-condenser with about $\frac{3}{4}$ square foot per lb. condensed per minute, and was said to require about $1\frac{1}{2}$ lb. of fresh condensing water per lb. of steam condensed; but there was no information as to the efficiency of the plan. The Wright condenser (page 197) was said to have $3\frac{1}{2}$ square feet of surface per I.H.P., equivalent to $10\frac{1}{2}$ square feet per lb. of steam condensed per minute, assuming a consumption of 20 lbs. of steam per I.H.P. per hour; but nothing was said about the results obtained.

The experiments referred to in page 199 he had been able to make through the kindness of Messrs. Whyte and Cooper of Dundee in altering pipes and connections. These experiments had been fully described in his report for 1892, to which allusion had been made; and his only object in now referring to them was to guard against a misapprehension which might arise from the figures quoted in Table 2, (page 200). It was there stated (line 9) that the storage tank F for the circulating water, Figs. 64 and 65, Plate 58, had a capacity of 1,830 lbs., or about 230 lbs. per lb. of steam condensed per minute. In the original report from which the figures were taken it had been pointed out that, owing to the alterations made in the arrangement of the circulating pipes for the purpose of the experiment, the discharge pipe C from the tank to the circulating pump was connected more than half way up the side of the tank: so that something like half the water in the tank was dead water, and the actual capacity of the tank was probably only about 115 lbs. instead of 230 lbs. per lb. of steam condensed per minute.

(Mr. Michael Longridge.)

Incidentally to an engine trial, he had been able to make some observations upon another condenser of similar design. Although the figures, which were also contained in his report for 1892 (page 69), were not so complete as those quoted in Table 2, they might nevertheless be of some use, and were therefore given in Table 4. The condenser consisted of 80 vertical cast-iron tubes, having 1,170 square feet of surface. The capacity of the storage tank for the circulating water was 40,000 lbs. The engine indicated an average of 75 H.P.

In another instance he had provided 2,000 square feet of surface and a condensing-tank capacity of about 17,500 lbs. for a compound engine driving a saw mill with a boiler pressure of 120 lbs. per square inch. At present the engine was lightly loaded, the power varying throughout the day between 60 and 100 I.H.P. The steam used was probably from 16 to 25 lbs. per minute, according to the load. Though he had made no observations on this condenser, he referred to it for two reasons: firstly, because he was told that in cold weather it could be worked without any water, when the load was light, say from 60 to 80 I.H.P.; and secondly, because the water from the hot well, instead of being returned to the boiler, was pumped into the condensing tank. This was the only fresh water used, and it was more than sufficient to replace that lost by evaporation, since a fair proportion of it ran to waste by the overflow. The condensed steam was not returned to the boiler on account of the grease which came with it from the cylinders. From the information he had received about this condenser it would appear that in cold weather a condenser would work without water if its surface were about 125 square feet per lb. of steam condensed per minute.

So far as his own experience went, he should say that with water from 35 to 40 square feet of surface were required per lb. of steam condensed per minute. Whether this extent of surface could be reduced by using brass tubes, corrugated tubes, indented tubes, or any of the other devices mentioned in the paper, or even to any material extent by fans, he greatly doubted; and he feared that condensers with such small surfaces as recommended by Theisen and

TABLE 4.—*Condenser with Vertical Cast-Iron Tubes.*

Date	1892	Sep. 7	Sep. 9	Sep. 14	Sep. 14	Sep. 15
Duration of experiment	minutes	81	89	139	116	133
Steam sent to condenser per minute	lbs.	24·6	26·8	25·7	20·6	22·8
Vacuum in condenser, per mercury gauge	inches	13·4	11·3	13·4	13·7	13·6
Initial temperature of circulating water	Fahr.	89	94	92	87	88
Final ,, ,, ,,	Fahr.	92	104	103	98	105
Mean ,, ,, ,,	Fahr.	90·5	99	97·5	92·5	96·5
Temperature of water in hot well	Fahr.	108	115	112·5	105	107
Mean difference of temperature inside and outside condenser	Fahr.	17·5	16	15	12·5	10·5
Condensing surface per lb. of steam condensed per minute	sq. ft.	45·7	43·6	45·5	57	51·4
Heat sent to condenser per hour	B.Th.U.	22,816	23,126	21,556	21,566	22,036
Heat transmitted per hour per square foot of condensing surface	B.Th.U.	19·5	19·8	18·4	18·4	18·9
Heat transmitted per hour per square foot of condensing surface per degree of mean difference of temp.	B.Th.U.	1·1	1·2	1·2	1·5	1·8

(Mr. Michael Longridge.)

Wright would prove unsuccessful. If the figures given in Table 3 (page 201) were to be depended on, the Row indented tube certainly promised some success; but he was not at all satisfied that the figures were to be depended on, because the vacuum was obtained by the induction of a steam jet, and it was not clear that some of the steam which issued from the jet did not come from the inside of the condensing tube.

He could not see how spiral deflectors inside the condensing tubes, or circulation through them in series instead of in parallel, could increase the transmission of heat. The theory of an uncondensed core was unsupported by any evidence; and the device of a counter current could not be applied, because the condensed steam inside the tubes and the water outside must both alike flow downwards. The position of the steam inlet however he thought might affect the efficiency of the condensing surface. The inlet ought in his opinion to be at the bottom of the condenser, as in Fig. 64, Plate 58, so that the oil and water which entered the condenser in no inconsiderable quantity with the steam, particularly when the exhaust pipe was long, might not be carried over the whole internal surface of the tubes; for the thicker and more extensive the coating of water upon this surface, the less efficient would the surface be in condensing the steam.

It had been mentioned by Mr. Donkin (page 209) that a considerable oily and greasy deposit had sometimes been found inside the condensing tubes. This however had not been his own experience. The condenser referred to in Table 2 (page 200) was clean inside when tested, though it had been in daily use for two years previously. Only last Saturday (22nd April) he had taken some of the bends off the ends of the tubes in a Ledward condenser which had been at work for five years, and had found no oil or grease inside. He had also asked Messrs. Douglas and Grant of Kirkcaldy to examine the inside of another condenser which had been at work in their neighbourhood for seven years, and they had reported that they had found no oil. It might indeed, he thought, be asserted as a fact that the oil from the cylinders was not deposited at all inside the condensing tubes, but was carried through them along with the

water which entered with the steam. It was generally supposed, and he had even heard it stated in evidence as a fact, that the oil which entered the main steam-pipe or valve chest of a steam engine from a sight-feed lubricator became incorporated with the steam in a fine spray or minute state of subdivision, converting the steam itself into a lubricant. But from what he had seen of difficulties in lubricating slide valves he was convinced that no such incorporation with the steam took place, but that the oil was carried into the cylinder and out of it upon the water which was always present with the steam ; and if this oily water entered an evaporative condenser at the bottom, as it ought to do, it would never get into the tubes at all. This suggested a question about the arrangement of the ordinary surface-condenser. Generally the water passed through the inside of the tubes, the steam entered at the top, and after condensation was drawn off from the bottom ; and although a certain proportion of the oil brought in with the steam was carried through to the boiler unless stopped by a special filter, a considerable proportion remained in the condenser, particularly upon the tubes just under the steam inlet; in both places the oil was inconvenient. Would it not then be better to let the exhaust pipe discharge into a well at the bottom of the condenser, as sketched in Figs. 84 and 85, Plate 64 ? or into a large separator before entering the condenser at the top ? so that the water and oil brought in with the exhaust steam might be collected in the well or separator, and be removed by a special pump. Such an arrangement he was satisfied would keep both boiler and condenser almost if not altogether free from oil.

He should be glad to know if any trial had ever been made of a wet blanket sheathing upon the tubes of an evaporative condenser. It seemed possible that such a covering would permit the use of a much stronger air-current than could be employed where the water simply ran down or over the tubes.

Mr. Leonard Andrews said the Wright evaporative condenser shown in Plate 53, or one much like it, had been in use in the electric-light station at Hastings for about twelve months, during which time many experiments had been made with it. No entirely

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satisfactory results had yet been obtained. As at first arranged, all the tubes, according to electrical phraseology, were in parallel; that is, the exhaust steam came in at the top, and passed down through the whole of the vertical brass tubes simultaneously in parallel currents, and the condensed water was taken out through the bottom chamber and the air cooler. Although the condenser was designed to evaporate 15,000 lbs. of water per hour, it was found that it evaporated only 6,000 lbs., and the vacuum was only about 15 inches of mercury. The area of the condensing surface was about 2,000 square feet. It was suggested at the time that the only way to get any better results from the tubes in parallel would be to increase the surface of the condenser by adding extra nests of tubes; but as he had found that a large number of tubes were quite cool even at the time of the heavy load, he concluded that to put more tubes in would be only to increase the number of cold tubes. It appeared that, as soon as the engine began working, the steam started going down certain of the tubes, and then stuck to those particular tubes for the remainder of the working, and would not go through the rest of the tubes, which consequently remained cold. Apparently the steam formed a partial vacuum in the tubes which it first entered, and thereby drew in more steam after it into these same tubes: so that certain of the tubes did all the work, while the others did nothing. It had therefore occurred to him that possibly by putting the tubes in series, and thereby crowding the steam through them all, a better result would be obtained. In the first instance only two bays or nests of tubes were tried in series: that is, the steam was brought down through the first nest and taken up again through the second, and thence to the air pump. That gave a somewhat better result. The plan was then tried of putting the whole four nests of tubes in series: the inlet for the exhaust steam was made at the top, and the steam passed down through the first nest, up through the second, down through the third, and up through the fourth, from the top of which a pipe led off to the air pump, while the water was drawn off from the bottom of all four nests. With this arrangement much more satisfactory results were obtained: the vacuum at the air pump was 23 inches, while about 15,000 lbs. of water was being

condensed per hour, which was the quantity the condenser was intended to condense. As no saving of steam was effected the first night, the engines were indicated to see what vacuum they had, and it was found to be only $3\frac{1}{2}$ to 4 inches at the engines, although it was 23 inches at the air pump. A number of cocks were then put on at various points, by means of which it was found that at the tops of the bays in the centre, that is the second and third bays, a vacuum of about 12 inches was obtained, while at the top of the first bay it was only $3\frac{1}{2}$ to 4 inches, the same as at the engines. Further investigation showed that this was due to the water having got up into the tubes, owing to the bottom boxes not being properly drained. A difficulty was experienced in draining the water away from the bottom of the tubes; for the proper working of the condenser it ought of course to be drained out from every one of the tubes. It had first been tried to accomplish this object by taking the bottom ends of the tubes in each bay into a box with a water seal at the bottom, and drawing off from beyond the seal to the air pump. An attendant had then to be stationed there, to keep the water level just the right height above the seal; because if the water got too low, the steam simply rushed through from box to box, blowing through the seal; while if the water got too high in the boxes, the vacuum immediately drew it up into the tubes, and it remained there for the rest of the working. The steam itself was sucked up through the tubes, notwithstanding the water in them, and apparently kept on condensing, and the condensed water kept on coming down into the bottom boxes. Thus the vacuum of only $3\frac{1}{2}$ to 4 inches was maintained at the exhaust-steam inlet, while at the same time the vacuum at the air pump was maintained at 23 inches. The difficulty was eventually got over by the method suggested in page 204, namely that, if the condensers were 30 feet or more above the air pump, as those at Hastings were, the condensed water should run down a pipe direct to the hot well, instead of to the air pump. Accordingly from each of the boxes at the bottom of the condensing tubes a separate pipe had been led down directly into the hot well, and it was now found that the water in these descending pipes exactly balanced the vacuum: in other words, when a high vacuum

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was obtained, the water was drawn up from the hot well into these drain-pipes; and as fast as more water was condensed in the condenser, an equal quantity just ran out from these drain-pipes, and the water in them balanced itself automatically. As further suggested in page 205, a jet or spray of cold water was next admitted into the cooler, Plate 53, and a pretty good vacuum was thereby obtained at the engines. The only thing was that, while there was about 20 inches vacuum at the air pump, there was only about 12 inches at the top part of the condenser and at the engines. These facts he obtained only two or three evenings ago, and he had not come to any conclusion upon them yet. What he wanted to know was what this difference of vacuum between the two ends of the condenser was due to: because he did not see how any water could possibly stay in the condensing tubes, now that each of the bottom boxes was drained directly into the hot well, as just described. The difference of vacuum could not therefore be due to water throttling the passage through the tubes; and he thought the tubes themselves were not too small. The air pipe to the cooler and air pump was three inches diameter, and seemed large enough to take off all the hot air. The only theory he had about it at present was that the hot air endeavoured to rise from the hot well to the top of the condenser, that is, through a height of about 35 feet, and that consequently 8 or 9 inches of vacuum was expended in sucking the air down against its tendency to rise. Perhaps some of the members might be able to suggest some other explanation, and what should be done to remedy the defect of vacuum at the engines.

A fan was fixed on the condenser, and was originally arranged at the top, as shown in Plate 53, but without any hood over the top of the condenser. It was found that the working of the fan did not make the slightest difference in the condensation; and it was thought possible that if a hood was put over the top it might make a difference. A great deal of expense was therefore incurred in encasing the top of the condenser over the edges down to the bottom of the water-distributing tanks, so that the air discharged by the fan had to be drawn through the spaces between the condensing tubes. It was still found however that the running of the fan made absolutely

no difference at all in the condensation. It was tried on two or three occasions, first a whole hour with the fan, and then an hour without the fan, on the same evening, so that the atmospheric conditions should not vary; but apparently it made absolutely no difference at all.

In page 204 it was recommended that horizontal condensers should be placed in a good position; and it appeared to him that the same recommendation applied equally to vertical-tube condensers. At Hastings the condenser was on the roof of a high building, and stood right out beyond everything else, excepting only where it was shielded from the wind by the chimney stack. It was put up by the side of the stack; and when the wind was in the direction from which the condenser was just sheltered by the stack, nothing like such good condensation was obtained as when the wind was blowing from any other direction.

Mr. Henry B. Spencer thought that, although the paper dealt only with evaporative condensers, and not with the whole question of condensation with a limited supply of water, it might be of interest if a reference were made to an alternative plan, in which the condensation of the steam was separated from the dissipation of the heat into the atmosphere, in contrast with the combined action of the evaporative condenser. In the past no doubt the evaporative condenser had been handicapped by the circumstance referred to by Mr. Longridge (page 210), that there had been so few records of its performance. The difficulties which had been experienced seemed to be due to the fact that sufficient cooling surface had not been allowed. On the Continent he believed there were a number of evaporative condensers doing good work, but in which a considerably larger surface was generally allowed than in this country. Another circumstance which had made a difference was that in this country the atmosphere was not generally so favourable to evaporation as it was on the Continent or in America. The average humidity of the atmosphere was much greater in England than in most parts of the Continent or America. In Fig. 83, Plate 63, was shown the Klein water cooler, with which he was best acquainted, and

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in which the cooling of the condensing water was kept entirely distinct from the condensation of the steam. E was the exhaust pipe from the engine to the jet condenser J, from which the discharged water passed along the pipe D to a trough T inside the base of the wooden tower W. Thence it fell upon the upper ends of a set of slightly inclined slats or shelves S, presenting an extended surface, down which it trickled in thin films to the lower ends. An upward draught was induced by the tower; the air came in at A, passed through the nest of shelves in close contact with the thin films of water, and escaped up the tower. From the shelves the water fell into a tank K, and was thence drawn again through the pipe I into the jet condenser J. The advantages of this plan over the evaporative condenser seemed to him to be, in the first place, that it enabled any ordinary condenser to be used, of which the action was much simpler than that of an evaporative condenser, and was also much better understood. In the next place the cooling, which was a different problem from maintaining a vacuum, could be dealt with as an entirely separate affair; the cooling surfaces could be packed much more closely together, a much larger surface for dissipating the heat could be allowed, and the surface could be made of much less expensive material. All the surface in the cooler was external; there was no question of transmission of heat through metal. The difficulty of deposit or scale was to a great extent overcome; there was no trouble from scale in the condenser, whether it was a surface condenser or a jet condenser. The temperature of the water was not raised sufficiently to cause the formation of scale; and even if dirt did accumulate on the surface of the cooler, it could affect its cooling efficiency only by choking up the spaces between the shelves. These however were arranged so that they could be easily cleaned. To other plans of cooling it was often an objection that extra power was required to work them; but for the cooler shown in Fig. 83, of which there were several working satisfactorily in England, no extra power at all was required. The vacuum in the condenser drew the water up from a depth of 8 or 10 feet; and then the water and condensed steam from the condenser were delivered by the air pump to the cooler. There was no head of water on the delivery valves

of the air pump, so that the vacuum was not interfered with thereby. This arrangement was not possible in all places. The disability attending a situation which was much cramped for space had to be paid for by expending more power to get the cooling required; by increasing the power and the height to which the water from the condenser was lifted, the cooling effect could be increased to almost any extent. On the other hand, if the power was to be kept down, more space must be allowed in which to do the cooling. The same condition applied also to evaporative condensers. In connection with the Klein cooler the object had always been as far as possible to avoid the use of fans. These could be avoided if the necessary space could be allowed; and then there was no expenditure of power except what might be necessary to raise the water to varying heights in the tower. It was not raised at all in the particular instance illustrated in Fig. 83, but was delivered to the base of the tower. In other arrangements it was raised to a height of from 16 to 25 feet, and trickled down over a succession of bars, laths, or grates, into the well at bottom. It was a sign of the times, he thought, that water-cooling arrangements were now finding favour in various works, in preference to evaporative condensers; and he trusted the hopes entertained of water cooling would be fully justified by the results, as he believed they would be.

Mr. C. J. Barley, having designed and erected the Ledward evaporative condenser and machinery at the Knightsbridge electric-lighting station, mentioned that one important point was the arrangement for separating the oil out of the condensed water. This was one of the difficulties in condensing; and in many instances where condensation was not adopted, it was because of the fear of the oil getting into the boilers. Ordinarily the only thing to do was to filter; and that was a troublesome process. At Knightsbridge there was a large separator in the main exhaust-pipe, between the engines and the condenser. It acted on the same principle as a steam separator between the boiler and the high-pressure cylinder. It threw down all the free oil, and the emulsion of oil and water which was drawn out of the engines. Good hydro-carbon cylinder-

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oil could not exist as a vapour at exhaust temperature. The dried exhaust steam only was then taken up into the evaporative condenser situated overhead; and the clean condensed water was taken from the condenser direct by a barometric pipe to the hot well, which was about 36 feet below the condenser bottom. The samples of the water he now exhibited had been taken from the condenser under various conditions of working. One of them had been taken with a load of 1,200 I.H.P. on the engines connected with the condenser, which was designed for 1,000 I.H.P. or 20,000 lbs. of steam per hour; this sample contained one part of oil to a million of water. It was rather a difficult matter to separate the oil and the water completely out of the steam. At first he had made a mistake in not fully realising the high velocity of the exhaust steam and water rushing along the long straight length of exhaust pipe into the separator. The velocity was so great, that the arrangement which was good enough for the ordinary high-pressure steam separator was altogether inadequate for the exhaust separator. A sample of the condensed water was shown, which had been taken before the separator was altered, and it would be seen there was a considerable quantity of oil in it. It was then noticed as a curious thing that, when working with the condenser just condensing the steam at atmospheric pressure and not under a vacuum, the separator acted fairly well, the condensed water being pretty clear of oil at full load: so that evidently its action was affected by the velocity of the steam and water entering it. A sample was also shown of the condensed water taken under a light load of only about 100 I.H.P., and it was seen that there was practically no oil at all in it; it looked quite clear.

Mr. Bryan Donkin asked what was the proportion of oil caught in the separator, as compared with the total quantity of oil used in the engines.

Mr. Barley replied that it was about 98 per cent. of the total oil used in the engine cylinders, in addition to a small amount of lubricant drawn from the crank chambers of the enclosed engines; and the water and oil caught in the separator were together about

8 per cent. of the total weight of feed-water supplied to the engines, the steam from the boilers being fairly dry but not superheated. Practically all the oil was caught in the separator; there was not more than one part of oil in a million of the condensed water taken from the condenser. There were many points however requiring careful attention in designing an arrangement of this kind. The oily water collected in the separator had to be got rid of. The condenser was some distance from the separator, and the remote ends of the eighteen parallel sections of condenser tubes were each about 200 feet run in series from the engines. There was consequently a higher pressure and temperature in the separator than at the remote end of the condenser whence the air suction-pipe was led off to the air pump. If therefore the bottom of the separator was connected by a pipe with the suction of the air pump to extract the water from the separator, the heat of this water would keep the air pump at a temperature and consequent pressure above that in the remote end of the condenser, and there would be no air suction at all from the condenser; the air would continually accumulate in the condenser. It was accordingly necessary for the water extracted from the separator to be cooled down by an auxiliary cooler before it was taken through the air pump. It was the only water taken through the air pump in this arrangement, and it was desirable to cool it as much as possible, because the cooler the air-pump suction-chamber was kept the better; for if this chamber was cool, it condensed the vapour out of the mixture of air and vapour drawn from the condenser. This rendered the air pump much more efficient, because its cylinders were filled at each stroke with air only, instead of with a mixture of air and vapour. Under these conditions a far smaller air pump than was generally used would suffice. The auxiliary cooler should be made like a small ordinary surface condenser, and through it the cold make-up for the circulating water drawn from the water main should be passed on its way to the circulating-water tanks overhead. It was most important to insert a U bend in the suction pipe between the separator and the air pump, and to make it lead down two feet or more below the bottom of the separator, and up again to the air pump, so as to form a water trap

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for preventing vapour from being drawn from the separator, seeing that the pressure in the separator might at full load be one lb. per square inch, or more, above that in the air-pump suction-chamber.

The necessity of having good joints had been referred to in page 205. Even with the best joints however, if proper provision were not made for the expansion of the long exhaust, condensed-water, and air pipes, leading to and from the condenser and connected with each section thereof, the result would not be satisfactory. Great attention had been paid to this matter at Knightsbridge, with most satisfactory results. After the final water-test, the condenser was used for some months in the winter merely condensing steam at atmospheric pressure, and was necessarily subjected to a range of temperature between boiling and freezing. When the air pump and connections were finished, a test was made to try the joints. The air was pumped out of the condenser, with the engines shut off, and a vacuum was obtained within an inch of that of the barometer. That was owing not altogether to the tightness of the joints, but partly also to the excellence of the Edwards air pump. It was highly desirable, if possible, to have a large hot well, and a good ball-cock or other device to prevent the water level from being reduced by irregular feed below the level of the outlet of the barometric pipe leading from the condenser to the hot well, which would cause a sudden loss of vacuum. After a twelve months' trial of the condensing apparatus at Knightsbridge, he was able to say that the cast-iron corrugated tubes of the Ledward condenser were easy to clean thoroughly of scale on the outside, and showed no sign of deterioration; there was no trace of oil in the condenser. The working of the whole required no extra labour, and effected a considerable economy. Moreover when working under vacuum the pulsation in the exhaust pipes ceased, and one cause of vibration was thus eliminated.

In Plate 65 were plotted observations taken at the Knightsbridge Station in a condenser test of $7\frac{1}{2}$ hours' duration on 10th March 1899 from 4.30 p.m. to 12.0 midnight. The temperature of the atmosphere was 49° Fahr., and the wet-bulb thermometer 44°, and the dew point was 38·6°; the barometer was 29·9 inches, and there

was a slight westerly wind. The quantity of water circulated was 30,000 gallons per hour, and the capacity of the circulating-water tanks was 22,000 gallons. The condenser contained 540 cast-iron corrugated Ledward tubes, 5 inches diameter inside the corrugations and 10 inches diameter over them outside; each tube was 5 feet long, containing 23 corrugations, and the metal was 3-8ths inch thick. The total evaporative surface exposed to the atmosphere was about 11,800 square feet. Every quarter of an hour during the test, observations were taken simultaneously of the weight of steam condensed per hour, of the temperature of the circulating water, and of the vacuum at three points:—namely at the air pump and remote ends of the condenser, plotted in curve A; at the condenser inlets, curve C; and at the engine-room exhaust-main, curve E. At the beginning of the test at 4.30 p.m. the weight of dry steam condensed was at the rate of 2,300 lbs. per hour. The load on the engines gradually increased up to a maximum of 26,000 lbs. of steam per hour at 7.0 p.m.; and then gradually decreased to 3,000 lbs. per hour at 12.0 midnight. Comparison should be made between the falling vacuum curves on the left of the maximum load, when the load was increasing, and the rising vacuum curves on the right, when the load was decreasing. On the increasing load, the condenser acted partly as an evaporative and partly as a surface condenser; whereas on the decreasing load, at and below 20,000 lbs. of steam condensed per hour, its cooling action was entirely evaporative. The condenser was designed for 20,000 lbs. of steam per hour; and comparing the vacuum obtained at this load in each case, it would be seen that the highest vacuum was 26·3 inches with surface and evaporative action in combination, the temperature of the circulating water being 84°. With evaporative action only, the highest vacuum was 21 inches, the circulating water being at 126°, and its temperature on the point of falling. Large storage water-tanks were a necessary safeguard in electric-lighting stations; and the above results showed they would lead to economy when condensing, by keeping up the vacuum over the peak of the load, thus reducing the size of condenser, the number of boilers under steam, and the coal bill. The large loss of vacuum between the remote ends

(Mr. C. J. Barley.)
of the condenser sections, the condenser inlets, and the engines, as shown by the three vacuum curves A C E, was evidently due to the throttling of the vapour. The size of the 18-inch exhaust-main was limited by the space available; but the loss across the condenser itself could have been eliminated by coupling up each section with two tubes in series and fifteen in parallel, instead of with thirty tubes in series.

The Edwards air pump was a vertical three-throw pump, with cylinders 12 inches diameter and 12 inches stroke, and was driven direct by a Lundell six-pole series-wound 200-volt electric motor running at 100 to 150 revolutions per minute. The armature wound upon a sleeve was keyed direct upon the overhanging continuation of the pump crank-shaft, without any outer bearing. The magnets were bolted to brackets cast on the pump casing, and were adjusted to take part of the weight of the armature off the bearing of the pump crank-shaft. The power required to drive the air pump, with normal quantity of air being extracted, was about 5 brake horse-power, and did not vary appreciably with the vacuum so long as the pump was kept cool; and a maximum of 7½ B.H.P. for between 5 inches and 12 inches of vacuum, when pumping the air out of the condenser before starting the engines.

Mr. W. H. Patchell said that, when he tried the evaporative condenser which was erected at the Charing Cross and Strand Electricity Supply station, a great deal more oil was got out of the condenser than went into the engine cylinders. The explanation was that the engines, like those at Knightsbridge, were enclosed, and running in oil, and he could not say how much oil found its way from the crank chamber into the condenser.

For anyone having to construct an evaporative condenser the paper was particularly valuable, showing in many instances how not to do it, which was as important as how to do it. With the exception of the Ledward cast-iron condenser at the Knightsbridge station (page 191) and the cast-iron condenser experimented upon by Mr. Longridge (Table 2, page 200), there were practically no data furnished in the paper as to the performances of evaporative condensers; and this was the information which was really

required at the present time. A condenser like that shown in Plate 53 had been ordered by his company to be put up in 1896, and it was not at work yet, having been through various changes of circumstance, somewhat like those encountered at Hastings by Mr. Andrews (page 218). The first trouble was with the condensing tubes, which were made with sliding joints and india-rubber rings at the top and at the bottom; the rings promptly failed. Then the makers who had it in hand tried making fast joints at the top by expanding the top ends of the tubes into the tube plate, and letting only the bottom ends slide. It seemed rather the wrong way to have the tubes hanging from the top, instead of standing on their base; but by fixing them in the tube plate at the top, and letting them slide at the bottom, the glands at the bottom were enabled to be drowned, so that if any little leakage occurred it was a leakage of water and not of air; and this advantage quite compensated for the tubes hanging instead of standing.

With regard to the advantage of an internal tube inside the condensing tube, as mentioned in page 186, he was sceptical. They had been inserted in his condenser, and from the absence of any effect upon the condensation he could not tell when they were in and when they were out. The cooling of steam in the condenser tubes he thought was generally looked upon as being rather like the cooling of hot gases passing through the tubes of a multitubular boiler; in the latter case the idea was that a central core of hot gases went straight through the tubes. But if the shrinkage of the steam against the condensing tubes was considered, it would be seen at once that—at the rate of condensation per square foot quoted by the author (page 196), namely 8 lbs. of steam per hour, and taking 120 cubic feet as the volume of 1 lb. of steam exhausted at about 12 lbs. per square inch below atmosphere—there was a motion of the steam towards the walls of the tubes at a velocity amounting to nearly one thousand feet an hour, quite apart from the motion of the steam in passing through the tubes. In contrast with this sort of compound motion of the steam, due to condensation against the tube surface, the hot gases passing along a boiler plate or through flue tubes underwent no shrinkage equivalent to that arising from condensation, to draw fresh hot gases into contact with the metal surface.

(Mr. W. H. Patchell.)

The distribution of the cooling water over the condensing tubes was a trouble, especially with vertical tubes; and he agreed with Mr. Donkin (page 208) that really the dirt was the worst trouble. He had not tried a chain of saucers on each tube, as shown in Fig. 3, Plate 41, but only a single saucer on each, as in Fig. 54, Plate 54; and possibly because a dust destructor was in the neighbourhood, they had promptly filled up with dirt; if not with dirt, they promptly filled up with scale out of the water. A pretty liberal clearance had been allowed for the water to get through; yet he had come to the conclusion that this was the best way of keeping the water off the tubes, for the saucers speedily became clogged up with dirt or scale, and then the water, instead of getting some sort of course down the outside of the tube, practically fell clear of it altogether. The best way he thought was to place water-deflecting boards between the tubes; then if the water fell off the tubes, it was caught on the boards and fell back again upon the tubes a little lower down. The wire netting, Fig. 2, Plate 41, was just as bad as the saucers, if not worse; the scale formed on the tube or netting, and instead of falling clear off the tube it fell on the netting, and was re-cemented there with freshly formed scale, so that a thicker scale was possible with the netting than without it. It was better he thought to supply a much larger quantity of cooling water over the tubes.

The arrangement of the condenser shown in Plate 58, which had been tested by Mr. Longridge (page 213), was the same he thought as one he had seen in Dundee some eight or nine years ago. The name however of the firm by whom it was made had been changed from Messrs. Cooper and Grieg to Messrs. Whyte and Cooper. At that time condensers of this kind were not at all uncommon in Dundee. At the electrical station one had been put up on the roof, in regard to which he had endeavoured to ascertain the working results, but had not succeeded in doing so.

Mention had been made by Mr. Andrews (page 219) of the benefit derived from what might be called the water leg, or as Mr. Barley had called it (page 226) the barometric pipe, from the condenser down to the hot well. In his own condenser he had done his best to

get the makers to take advantage of the 30 to 35 feet depth from the bottom box of the condenser down to the hot well; but he had not succeeded in getting them to do so. They had insisted on drawing off the air from the top of the condenser and the water from the bottom through the same pipe, which delivered its contents to the air pump.

The condensers described in the paper practically completed the list of evaporative condensers, if the Cochrane cylindrical condenser mentioned by Mr. Longridge (page 211) were added thereto. The only place where he had seen that condenser working was Messrs. Siemens' works at Woolwich. Some information had also been given in a short paper which had been prepared for the Chicago meeting of the American Society of Mechanical Engineers in 1893 (Transactions, vol. 14, page 690) by the late Mr. James H. Fitts, professor of mechanics and physics in the Virginia Agricultural and Mechanical College of Blacksburg, Virginia, who had there made a condenser with horizontal brass tubes wholly submerged in shallow troughs of cooling water; the plan was probably that of which Mr. Donkin had mentioned (page 210) that he had read. There were altogether 210 tubes, each No. 20 B.W.G. or 0·036 inch thick, $\frac{3}{4}$ inch external diameter, and 4 ft. $9\frac{1}{2}$ ins. long; and there were twenty-seven troughs, arranged one above another, with 8 tubes each in 21 of the troughs and 7 each in the remaining 6 troughs; all the tubes in each trough were on the same level, and opened at each end into a vertical steam-chamber. One chamber was divided at the middle of its height by a transverse diaphragm, so that the exhaust steam entering at the top traversed the tubes in the upper half of the condenser and returned through those in the lower half, the condensed water being drawn off from the bottom. There had been such trouble however in getting the exhaust pipe tight that Mr. Fitts had been obliged to give up all idea of using the condenser on his college engine before the Chicago meeting; and the figures given in his paper related to steam generated in a boiler close by, at 60 to 70 lbs. pressure per square inch, and condensed direct in the condenser. The general conclusion arrived at from a number of trials of several hours'

(Mr. W. H. Patchell.)

duration was that the cooling water required was practically equal in weight to the steam condensed. Mr. Fitts had further plotted two interesting curves, showing the effect of the temperature of the cooling water upon the rate of evaporation when working the condenser with an exhausting fan, and also without the fan, that is, in still air. In both cases the barometer averaged 28 inches of mercury, and the vacuum $16\frac{1}{2}$ inches. With the cooling water at a temperature of 60° F., the evaporation in still air was about 0·1 lb. per square foot per hour; and on heating the water up to 180°, it evaporated at the rate of 2·75 lbs. per square foot per hour. With the exhausting fan drawing air horizontally across the water troughs at a velocity of 2,300 feet a minute, the evaporation was 0·8 lb. at 93°, and 9·5 lbs. at 160°; without the fan it was 1·45 lbs. at 160°. Here therefore it could not be said that the fan was of but little use (page 203). The first mention he had met with of a proposal to attach a fan to an air surface condenser was in "Engineering," vol. 7, 1869, pages 185 and 187–8, which was of some interest because several years later the use of a fan for this purpose had been claimed as a novelty in England. Also in vol. 9, 1870, page 383, there was a description of an evaporative surface condenser designed by M. Jean François Cail of Paris, which was well worth reading.

The President was sure the Members would be interested to hear from Professor Goss, of Purdue University, Lafayette, Indiana, U.S.A., who was on a visit to this country, anything he could tell them in regard to American experience with evaporative condensers.

Professor W. F. M. Goss said that, so far as he knew, the individual evaporative condenser which had been referred to by Mr. Patchell (page 231), as having formed the subject of a paper presented by Mr. Fitts at the Chicago meeting of the American Society of Mechanical Engineers, was the only one that had been worked at all in America. That, as he remembered, was a small condenser, constructed entirely for experimental purposes; and he did not know of any evaporative condenser having been used commercially in America. Cooling towers however were used in

connection with surface condensers; but on the whole the condenser had not received the attention in America that it had evidently received in England. Many large works had been running with the exhaust going into the atmosphere, in almost every town and city where steam engines were used. With regard to the cooling towers, the practice in America had settled down to the use of unglazed tiles inside the tower, instead of the slanting wooden slabs or shelves which had been described by Mr. Spencer (page 222) and were shown in Fig. 83. Cylindrical tiles of 4 to 6 inches diameter were used, in lengths of about 1 foot, and were placed standing on end in courses, and breaking joint in the successive courses. It would be seen that water which was sprayed from the top of such a tower was well divided, and was kept divided throughout its course to the bottom of the tower. Water coolers constructed of horizontal tubes were also used in America, but were not employed as condensers. They were used for cooling the jacket water of gas engines, and also of course in connection with refrigerating machinery.

The President had hoped the meeting would have the pleasure of the presence of Sir Frederick Bramwell, who had long ago had some experience in this mode of condensing. Unfortunately he was not able to be present; but Mr. Williams would offer some remarks on his behalf.

Mr. Hal Williams said the essence of the success of the evaporative condenser appeared to lie in the distribution of the water over the condensing tubes. Several arrangements of distributing troughs were illustrated in the paper, but that shown in Figs. 11 and 12, Plate 42, was the only one which seemed to him to approach in any way to what was found by experience to be best: namely a top slotted pipe placed over the top of the condenser tubes, and supplied with water from a tank placed in the middle of its length. It was first introduced into this country he believed by Messrs. L. Sterne and Co. of Glasgow, in connection with their ammonia condensers; and it had been used both for that purpose, and also in a slightly modified form for other condensers. In Figs. 87 and 88, Plate 66,

(Mr. Hal Williams.)

were shown an elevation and plan, and in Fig. 89, Plate 67, a side elevation of the ammonia and steam condensing arrangements in connection with a liquor-cooling plant, which had been put up by Messrs. Bramwell and Harris at Messrs. Meux's brewery in London. The ammonia condenser was placed on the top of a staging on the roof of the engine house, and the cooling water was pumped into a tank in the middle of the length of the condenser, and flowed both ways through the slotted pipes, running down over the condenser tubes into a tank beneath them. Thence it was delivered upon the top of the steam condenser, situated underneath the ammonia condenser; and after flowing down over the steam-condensing tubes it was cooled artificially in readiness for being used over again upon the ammonia condenser. It would be seen that the steam condensers were placed not directly under the ammonia condensers, but diagonally; they were so arranged in order that a duplicate of either condenser might be put in at a future time, if desired; and also in order that the steam arising from the steam condenser should not impinge directly upon the tubes of the ammonia condenser. One of the great drawbacks to the more extensive introduction of evaporative condensers was the large amount of steam evaporated from the outside of the tubes, which produced what he believed Sir Frederick Bramwell had once called a "washing day" effect. The figures quoted by Mr. Patchell (page 232) from the tests of an experimental evaporative condenser at the Agricultural College in Virginia showed rather conclusively the value of taking the utmost advantage of the latent heat by evaporating the water from the outside of the condenser. It would appear that a better result might be obtained by passing a smaller quantity of water over the tubes and evaporating nearly the whole of it, than by pouring over them a larger quantity of which so much less was evaporated. The difference of opinion that existed on this point was rather clearly shown by the fact that the Fraser condenser used he believed from 40 to 50 lbs. of cooling water per lb. of steam condensed, the Theisen from 20 to 25 lbs., and the Royle condenser from 5 to 10 lbs. only.

A plan of economising the condensing water had been used in several places by Messrs. Bramwell and Harris, and had always been

found to work successfully. But frequently the condensing water was found to be exceedingly hard and dirty; and this seemed to be one of the greatest troubles with evaporative condensers. The carbonate of lime coated the outside of the condensing tubes, and deteriorated their conductivity considerably. The simplest way of getting rid of it, as suggested in the paper (page 204), was found to be by turning off the cooling water and allowing the exhaust steam to expand the tubes; the scale could then easily be removed by means of a wire brush. One of the most important points in designing an evaporative condenser was to keep the tubes a sufficient distance apart, so that they could easily be got at everywhere for cleaning, and could readily be removed and replaced.

The diagram, Fig. 90, Plate 67, was rather interesting as representing he believed absolutely the first evaporative condenser that was ever introduced. It had been designed by Pontifex in 1836, and was used in connection with an apparatus for concentrating sugar juice. The vacuum pan V was heated in the ordinary way by a steam worm; and the steam rising from the partly concentrated liquor therein passed through the tubes of the evaporative condenser E, where it was condensed by the weaker juice to be concentrated, which flowed out from the tank T, and was distributed by the trough D over the tubes of the condenser, and trickled down over them into the receiver R, whence it flowed into the cisterns C. From these it was drawn up by the vacuum into the measuring vessel M, and thence delivered into the vacuum pan V. The condensed steam from the inside of the evaporative condenser flowed away from the bottom at A to the air pump.

Mr. WILLIAM BROWN said the Cochrane cylindrical condenser referred to by Mr. Longridge (page 211) and Mr. Patchell (page 231) had been in use at Messrs. Siemens' Telegraph Works at Woolwich for twenty-six years. It consisted of a number of vertical cast-iron double cylinders, one inside the other, as shown in Figs. 91 to 93, Plate 68, each 12 feet high; the outer was 44½ inches diameter outside, and the inner 40 inches diameter inside; between them was an annular space of about 7-8ths of an inch, into which the exhaust

(Mr. W. Brown.)

steam was led at the top, the condensed water being drawn off from the bottom. The cooling water was allowed to run down the outside of the outer cylinder and the inside of the inner, from an annular trough at the top into a similar trough at bottom. One square foot of surface sufficed to condense about $1\frac{1}{2}$ lb. of steam per hour. The first portion of the condenser was erected in 1873, and consisted of eight double cylinders; by additions made in 1880 and again in 1881 it had been extended to its present size, consisting of twenty-seven double cylinders. These were capable of dealing with 550 I.H.P., or of condensing 11,000 lbs. of steam per hour and producing a vacuum of 23 inches of mercury, when the cooling water was circulated at the rate of 24,000 gallons per hour over the whole condenser. The cooling water, obtained from the Kent Water Works, was hard, containing as much as 30 grains of solid matter per gallon; it produced a heavy deposit on the condensing cylinders at the rate of about 3-8ths inch thickness per annum. In order to remove the deposit more easily, a certain amount of boiler composition was added to the cooling water, and the cylinders were periodically scaled all over. The floor space occupied per I.H.P. was 2 square feet; and the weight of the condenser was 16 cwts. per I.H.P., including the connecting pipes. Although perhaps seeming somewhat out of date, the condenser had an important advantage in the ease with which it could be cleaned: nothing could be more simple than the cleaning, because a man could get all round the whole of the cylinders both outside and inside; and the outside surfaces could be cleaned while the condenser was in use. At the present time all the cylinders were practically as good as the day they were erected; and the cost of maintenance had been trifling, owing to the small amount of repairs necessary. A third advantage was the small consumption of cooling water, the evaporation amounting to not more than two-thirds of the weight of the steam condensed. There were two serious drawbacks. One was the extent of floor space occupied, which amounted to as much as 40 square feet for each double cylinder. The other was the weight, which was so great in consequence of the size of the cast-iron cylinders, and was further augmented by the thickness of the accumulation of scale

upon them. Some of them had been taken down and thoroughly cleaned in 1894; and it was then found that, although they were practically as efficient at that time as when first put up, scale of such thickness had formed in places as to show that if no scaling were done on them an allowance would have to be made for increase of weight amounting to as much as one ton for each double cylinder in the whole condenser. Consequently the structure to carry them had to be carefully considered. In view of the facility for cleaning and repairing he thought there was nothing better, where there was plenty of space. This condenser stood in about the same relation to the more modern evaporative condensers described in the paper as did the old egg-ended boiler to the modern water-tube boiler, in regard to repairs and cleaning.

Mr. OLDHAM quite agreed that one of the principal difficulties which had to be dealt with in evaporative condensers was the dirt on the outside of the tubes. Of vertical condensers with brass tubes sliding through the top water-tank he did not know one that had been working satisfactorily; the narrow annular space through which the water flowed down over the tube often got filled with dirt, and then the tube was left dry, without any cooling water flowing over it. Moreover the pitch of the tubes was often so small that nothing could be got in between them to scrape the scale off: although the scale did not stick to the brass tubes as it did to the cast-iron. The horizontal condenser shown in Plate 47, which might be made with wrought-iron or cast-iron tubes, could be got all round for removing the scale; and it must be cleaned periodically, or efficient results were not obtained. In that condenser the spaces were more than 1 foot clear, so that about once a month or so, with a wire brush for a scraper, the dirt could be removed from the tubes. It was found that in the cast-iron condensers the scale stuck to the tubes much more than it did on wrought-iron tubes; from the latter it could easily be removed by tapping the tubes, when it broke away quickly; but from cast-iron tubes it did not.

Cylindrical tubes were considered by Mr. Donkin (page 209) to be better than tubes of complicated section; and perhaps there was an

(Mr. Oldham.)

advantage in having cylindrical tubes, because in tubes with grooves or depressions the latter often got filled with scale and dirt, although if ample room were allowed the Kynoch tube of heart section, shown in Figs. 81 and 82, Plate 63, could be easily cleaned. If the ends of horizontal iron tubes were expanded into the tube-plates, they answered as well as flanged joints, and in some cases better.

The power required for driving a fan in connection with a condenser (page 210) was about 2 to 3 per cent. of the total engine power, as far as his own experience went. With regard to the low value assigned to fans (page 203), it was true that in Mr. Row's experiments (Table 3, page 201) the condensation was increased 50 per cent. by the air current; and in the experiments quoted by Mr. Patchell (page 232) the value of the fan appeared to be even greater. But these results were experimental; and although fans designed specially for experimental purposes might give such favourable results, yet in practice, when fans were applied in the manner shown in the five examples, Figs. 74 to 78, Plate 61, the value of the air current was practically nullified, and all that the fans were doing was simply wafting a gentle movement of air through the condenser. Sometimes the result was not more than 1 per cent. increase of condensation; and Mr. Andrews had found (page 220) that when the fan was running the result obtained was no better than when the fan was idle. In an experimental condenser containing a great nest of tubes he could imagine that a fan might increase the condensation as much as 50 per cent.; and the condenser mentioned by Mr. Patchell (page 231) as having been tried in America had been stated by Professor Goss (page 232) to be entirely an experimental apparatus.

The remarks made about getting the oil out of the exhaust steam (pages 216 and 223) were highly important. It was well known what great mischief oil did when it got into a boiler.

The plan of putting wet blankets over the condenser tubes, about which Mr. Longridge had enquired (page 217), had been tried in a Theisen condenser. A special fabric was wrapped round each of the tubes, so as to keep the cooling water close against them; but he had not heard any particulars as to the results. It had also been proposed to put a special fabric—either wire-netting or felt or

rough canvas—for a wrapping round the Kynoch heart-shaped tube shown in Fig. 82, Plate 63; but the very alternatives mentioned in the proposal seemed to him to betray ignorance of the principle of evaporative condensers.

In the first brass-tube evaporative condensers which had been erected, the extent of condensing surface provided had been 1 square foot per 10 lbs. of steam condensed per hour, or 6 square feet per lb. of steam condensed per minute, as quoted by Mr. Longridge (page 212); but how that proportion had been arrived at he could not understand. That was about the surface provided in marine surface-condensers, and he had not been able to find out how it ever came to be adopted for evaporative condensers. All the makers of brass-tube evaporative condensers seemed to have been led away by that proportion, and all appeared to have adopted it; Mr. Theisen he thought was responsible for its adoption in the first instance. In experiments on the Continent marvellous results were said to have been obtained from evaporative condensers, which engineers in this country had not been able to investigate, owing to the expense and time involved. Those who had accepted as the standard a condensation of 10 lbs. of steam per hour per square foot of surface for vertical brass-tube condensers with fans had been led into serious difficulties. That extent of surface would be large enough if the fan doubled the condensing efficiency; but it did not. A number of electrical engineers had had to incur the expense of making experiments for themselves on this matter with this kind of condenser, and other engineers had to thank them for it. There was no doubt that a horizontal evaporative condenser with wrought-iron tubes, having about 1 square foot per 3 lbs. of steam to be condensed per hour, would do its work efficiently, without requiring any fan at all. As long as there was a good quantity of cooling water, say 10 to 20 times the weight of the steam condensed, he thought such a condenser would answer all requirements.

A large amount of steam was given off from the top of an evaporative condenser; but that was certainly what occurred wherever steam engines were at work non-condensing. If it was required to cool

(Mr. Oldham.)

the water for a jet condenser in a cooling tower, a large volume of steam came out of the top of the tower, and was blown about; but this was not so much of a nuisance as the steam coming direct from the exhaust pipe of a non-condensing engine, because the steam from the tower was divided much more finely, and was sooner condensed round about. A cooling tower seemed to him not to be required with an evaporative condenser, because if it was put up there were two appliances for doing the work of one. In Glasgow there had recently been erected a cooling tower 12 feet diameter and 31 feet high for cooling the water for a surface condenser for condensing 10,000 lbs. of steam per hour, or 500 H.P. In addition there were the surface condenser itself and air pump, the circulating pump for the condenser, and also pumps for circulating the water in the tower. The ground space occupied by the cooling tower alone was 1 square foot per 5 H.P.; and as some evaporative condensers took but little more space than this, it would appear that not only would a large amount of room be taken by the cooling tower, but there would be two separate sets of appliances for doing what an evaporative condenser could do at once by itself. In some of the cooling towers which were constructed with galvanised netting inside, the netting rotted away quickly. When it was possible to have condensers which did the work without the aid of a cooling tower, he did not see that the cooling tower was any advantage. [See also page 252.]

The President trusted the discussion upon the present paper on evaporative condensers would lead to another paper being written on the interesting subject of water cooling, in order that it might be realised more fully what could be achieved in practice by the latter plan in comparison with the former.

Mr. Horace Boot, Borough Electrical Engineer, Tunbridge Wells, wrote that he did not agree with the statement in page 185 that the amount of condensing water used with an evaporative condenser might be from 25 to 30 per cent. less than the amount of feed-water used when the engines were non-condensing; the reduction he considered should be from 10 to 15 per cent. only. The works at Tunbridge Wells were one of the first to adopt the Wright evaporative condenser; and it might be interesting therefore to give briefly the results of a test conducted in May 1898. The tubes are of brass, sixty in number, of No. 19 wire-gauge or 0·04 inch thickness, and $2\frac{1}{8}$ inches diameter. The test was conducted for six hours under a steady load giving 10,680 lbs. of steam per hour to be condensed. The vacuum maintained during this time was 21·45 inches of mercury, the guarantee being 24 inches. The condenser was new and clean; it had been previously tried, and had proved a failure, but by subsequent alterations had been brought up to the above state of efficiency. The temperature of the cooling water in the sump was 130° F.; but in order to get good results the writer considers it should not exceed 120°. In another test, made under nearly the same atmospheric conditions after the condenser had been working six months continuously, it was found that it had deteriorated, and that in order to maintain the same vacuum it was capable of condensing only some 7,000 lbs. of steam per hour, although the tubes were not particularly dirty. The rapid deterioration however is a great drawback to evaporative condensers.

The principal difficulty seems to be to get the cooling water to distribute itself evenly all over the tubes. Several different plans were tried, and he finally came back to wire netting, Fig. 2, Plate 41. The method of cleaning suggested in page 188, by moving the netting up and down, is quite impracticable. A neat method is by passing steam through the tubes without water, thereby expanding them sufficiently to cause the scale to chip off inside and outside; and on then brushing the tubes, all the scale falls to the bottom.

Wrapping a blanket round the tubes, which Mr. Longridge asked about (page 217), was tried by the writer; but the only result was that bits of the blanket had to be picked out of the valves of the circulating pump.

(Mr. Horace Boot.)

Sufficient attention he thinks is not given to the power absorbed by air pumps and circulating pumps, and to the capital outlay involved in comparison with the saving effected when condensing. If more consideration were bestowed upon these points, a far greater saving could be effected by condensing than is at present realised. With many evaporative condensers it seems doubtful whether any actual saving whatever is effected, owing mainly to the inefficiency of the pumps and to the power expended in circulating the cooling water.

Mr. Donald Enock wrote that the author had mentioned (page 240) that some cooling towers were constructed with galvanized wire mats, over which the water was distributed, and that these mats rotted away quickly. There is only one kind of tower at the present time, the writer believes, which has this plan in use, namely the Barnard-Wheeler tower; and one set of wire mats has been in continuous use for five years in one of these towers in connection with a tramway. In this instance the water is slightly brackish, and there is no sign of either wear or rotting from use or exposure. As far as he knows there are no instances of the mats having deteriorated in any way. They are of steel wire and small mesh, galvanized after being woven; and each intersection is covered with a solid mass of spelter, thus protecting the parts most open to corrosion.

The remark of Mr. Andrews, that the use of a fan made practically no difference in the efficiency of his evaporative condenser (page 220), may well apply to evaporative condensers in general, for the reason that it is practically impossible to make a fan large enough to distribute the air current effectively over all parts of the condenser. When in an exposed position, the evaporative condenser will do much better with natural draught, as opposed to forced or induced draught, because the casing and chimney required for the latter are too cumbersome for practical use, excepting in the Wright and other similar condensers, which being vertical are more adapted for the employment of a fan; but if cased in for a fan they are useless for natural draught.

There always remains the fact however that on a damp muggy day, when no air is moving, an evaporative condenser cannot be expected to work efficiently, and reminds others besides Sir Frederick Bramwell of a general washing-day (page 234). An instance is furnished by the apparatus on the roof of the Brighton central electric station; alongside is a Barnard tower doing excellent work, which is itself a standing proof of the advantages of a surface condenser and water-cooling tower combined, in comparison with an evaporative condenser. From an examination of the two plans where in use in this country, the writer is satisfied that, in regard to weight and ground space taken together, and economy and ease of working, an evaporative condenser is not to be compared with a combined surface-condenser and water-cooling tower.

The special points to notice in water-cooling towers are that the water should be divided into as thin sheets as possible, and be exposed on each side of the sheet to a large quantity of air at a low speed. Those towers in which the free passage of air is impeded by overlapping tiles or wooden shingles can never give complete satisfaction, because of the obstruction thus offered to the air.

In the discussion upon a paper read to the Cleveland Institution of Engineers by Mr. Horace W. Jarvis of Middlesbrough, the following particulars were given by Mr. Marston of Middlesbrough (Proceedings 1899, page 91), respecting the ground space occupied per I.H.P. by different methods of water cooling:—deep pond, 39 square feet; pond with sills or terraces like Whitwell's, 13; Körting spray cooler, 7; Klein open cooler, 2·3 square feet. The cost per I.H.P. was:—deep pond, £3 15*s.*; Whitwell pond, £2; Körting sprayer, 17*s.* 6*d.*; Klein open cooler, 13*s.* 6*d.*

The writer is informed by Mr. Reavell, of the Blake Knowles and Barnard-Wheeler tower cooler, that a water-cooling tower of any capacity required can be erected at the rate of 2½ cwts. per square foot of its base, including supply pump and water; and that at the present time a cooling tower is in use, mounted on a roof two storeys high, and having a cooling capacity of 8 horse-power per square foot of base, while another is being erected with a cooling capacity of 16 horse-power per square foot of base.

Mr. Robert Hammond wrote that electrical engineers had frequently to erect generating works on sites where ample water for condensing was not available; and at the present time he was himself concerned with designs for three places where the problem of condensing at a distance from either river or canal had to be dealt with. The impression he had derived from the paper and discussion was that the evaporative condenser must be avoided, as sufficient reliance could not yet be placed upon it. There was one point not dealt with in the paper, upon which he should like to have some information: namely, what was the actual monetary saving realised by the use of an evaporative condenser. Naturally the main object in condensing the steam was to effect a saving in coal; and he should be glad to know whether sufficient data had been obtained for stating, on the one hand, the value of coal saved during twelve months, presuming that the boilers supplying the main engine were also supplying the air and circulating pumps; and on the other hand, the annual interest on capital expenditure, the annual sum for depreciation, and the annual amount of wages and repairs.

Mr. H. H. Rhodes James wrote that, although the paper gives much information regarding the construction of evaporative condensers, it contains little as to their performance, which latter appears in some instances to be hardly satisfactory. It would be of interest to have some data as to the vacuum obtained with a well designed condenser under different conditions of atmosphere and load. Probably a vacuum of about 20 inches of mercury would be considered highly satisfactory; and it is doubtful whether a higher vacuum would be maintained for any length of time, unless under a light load.

With regard to the statement in page 197, that a 16 H.P. engine drives the circulating pump and fans for condensers dealing with 3,000 H.P., it seems questionable whether the power required for driving the fans would not greatly exceed 2 per cent. of the total engine power (page 204), at all events in comparatively small installations.

The average cost of the evaporative condenser (page 206) appears to be considerably over 20*s*. per I.H.P. for small sizes; and it may perhaps be of interest to give some figures of the estimated cost of a 100 H.P. condenser with horizontal cast-iron corrugated tubes. The condenser alone would cost £175 for this power; belt-driven air and circulating pumps would increase the amount to £270; adding to this the cost of a small engine or motor, the connecting pipes, cooling-water tank, girders for carrying the condenser, and the erection of the whole, the total might be put at from £350 to £400, exclusive of extra outlay on the special design of roof. The space required for such a condenser would be about 18 feet by 13 feet or 234 square feet, against 90 square feet given in page 192 for this amount of power. The vacuum was expected by the makers to be from 22 to 24 inches of mercury. In framing estimates for various kinds of these condensers it would therefore appear desirable to allow at least £3 per H.P., including therein the cost of pumps, connecting pipes, and erection. For larger condensers it is doubtful whether this cost could be reduced, owing to the increased weight both of the condenser itself and of the pipe work. The practice of stating the cost of the condenser alone by itself appears likely to lead to erroneous ideas of the commercial value of the whole.

Mr. T. R. Murray wrote that most designers of evaporative condensers have adhered to some variety of the pipe form, which however he considers is not by any means the best adapted to meet the requirements. The chief objects to be attained in an evaporative condenser are the following:—firstly, to bring the steam into contact with the cooling surface as completely as possible; secondly, to abstract heat from the cooling surface by evaporating from its external surface a certain proportion of a thin film of constantly circulating water; thirdly, to keep up a constant and steady rate of evaporation; fourthly, to ensure that all power expended is thoroughly utilised; and lastly, to arrange all the parts so as to be readily accessible for examination and cleaning. Finding how defective in some or all of these respects are the various kinds of condensers in use, he some time ago devised and constructed on

(Mr. T. R. Murray.)
different lines an experimental condenser, which gave remarkably good results. Instead of tubes, flat cells of thin corrugated brass sheeting are used, as shown in Figs. 94 and 95, Plate 68; the condensation takes place in their narrow internal spaces, and the cooling water flows in a thin film over their external surfaces. The steam is thus brought into intimate contact with the cooling surface, and there is no core of uncondensed steam, as there is believed to be so frequently in tubes. Special brass stay-strips are arranged inside the cells, to prevent them from collapsing; and a safety valve is placed on the exhaust inlet pipe, to provide against internal pressure; for the latter purpose also distance pieces are arranged between the cells. The flat cells are placed upright and parallel to one another inside a casing, with a narrow space between each; and through these narrow spaces passes a constant upward current of air from a fan, meeting and thoroughly intermingling with the descending water, thus ensuring that every particle of air and water does its proper work. This is an important matter; and much of the failure to appreciate the use of fans for evaporative condensing is due to their being generally so arranged that a large percentage of their work is wasted in circulating air which never comes into contact with the water at all, as exemplified in the condenser referred to by Mr. Andrews (page 220), where the fan was so inefficient that it made no difference whether it was running or not. The results obtained with the experimental condenser of this construction are given in Table 5: the steam supply was taken from the exhaust of a single-cylinder slide-valve engine; the area of the condensing surface was 114 square feet; the weight of water circulated was ten times the weight of steam condensed; the make-up water was taken from the main; the temperature readings were taken every ten minutes; and the Blackman air propeller of 24 inches diameter ran at 800 revolutions per minute. Provision was not made in these experiments for obtaining a vacuum, because this would of course be exactly the same as would be obtained from a surface-condenser delivering condensed steam at the same temperatures.

TABLE 5. -*Murray Evaporative Condenser, Figs.* 94 *and* 95, *Plate* 68.

Date of experiment . . 1898	March	4	10	14	23	24
Duration of experiment . .	hours	$3\frac{1}{2}$	8	$3\frac{1}{2}$	2	$4\frac{1}{2}$
Temperature of condensed Steam leaving condenser . .	Fahr.	147°	122°	173°	136°	122°
Temperature of circulating Water entering condenser . .	Fahr.	119°	125°	125°	—	—
Temperature of make-up Water .	Fahr.	40°	40°	40°	41°	41°
Temperature of Air entering fan .	Fahr.	50°	55°	47°	58°	55°
Temperature of Vapour escaping from condenser . . .	Fahr.	146°	131°	161°	126°	118°
Weight of Steam condensed per hour	lbs.	1,576	1,080	2,073	1,336	1,032
Weight of make-up Water added per hour	lbs.	1,275	794	1,575	1,080	771

A condenser on this plan for 250 H.P. is now being made by the Mirrlees Watson and Yaryan Co., Glasgow, with full arrangements for completely testing it, and with separate electric motors for driving the fan, the air pump, and the circulating pump, so that the power consumed by each may be accurately ascertained. The expansion and contraction of the corrugated sheets prevent the formation of scale; and any condensing section can be readily removed and opened for cleaning. Owing to the fact that no space is wasted, the room occupied by the condenser is reduced to a minimum.

Mr. William Schönheyder wrote that an early pioneer in evaporative condensers was the late Mr. E. A. Cowper, who continually urged their great advantage; he believes it was owing to his advocacy that Messrs. Siemens Brothers of Woolwich erected twenty-six years ago the Cochrane condensers so highly spoken of by Mr. William Brown (page 235). Eight similar condensers were previously fixed in 1870, also under Mr. Cowper's directions, at Messrs. Anthony Gibb's works near the Victoria Docks. An evaporative condenser with horizontal tubes was also supplied by him at Messrs. De la Rue's works in Finsbury; and no doubt he erected many others (Proceedings 1862, page 119). But in spite of his perseverance, it is only in recent years that steam users have come to adopt them more generally. In 1868 the writer remembers seeing an evaporative condenser with horizontal tubes at the saw

(Mr. William Schönheyder.)

mills of Messrs. Hudson and Carr near Vauxhall Bridge, which even then was far from being new.

In Fig. 46, Plate 52, and also in Plates 50 and 53, is shown a cooler for reducing the temperature of the air before it reaches the air pump, evidently with the object of improving the vacuum; but beyond a slight shrinkage in the volume of the air, whereby the air pump would be rendered a little more effective, he fails to see any advantage in the arrangement, for it is clear a vacuum cannot thereby be obtained better than that due to the general temperature of the body of vapour in the condenser, and it will always be somewhat worse. Can any trustworthy data be furnished to prove the benefit of such a cooler for the air only?

It would also be interesting and useful to have records of experiments as to the benefits derived from the internal spiral distributors, Fig. 15, Plate 42, which are said to have been devised by Messrs. John Fraser and Son (page 186). More than thirty years ago he made several experiments in this direction, but failed to find any advantage from their use.

In the Kensington and Knightsbridge condenser, Figs. 35 and 36, Plate 46, the branch pipes from the main exhaust are shown rising up to the top of the condenser. This he considers cannot be good practice, as it necessitates a separate drain from the main exhaust, which should itself be at the highest level, so as to drain into the condenser tubes. It is also incorrect in his opinion to allow the air-pump suction to rise after leaving the lower part of the condenser; as air is heavier than vapour of water at the same pressure and temperature, it should always be given a continuous falling gradient to the air pump. The troubles met with by Mr. Andrews at Hastings (page 218) he fears may have arisen partly from neglect of this fact. The practice of providing a drain pipe for the condensed steam, separate from that conveying the air, seems to present no advantage, because the volume of condensed steam is so small compared with the volume of air to be pumped, that the separation of the water will not materially reduce the pump capacity required for pumping out the air; and moreover the water in the pump helps to seal the valves and bucket, and thus prevents loss by

leakages in the air pump. For the same reasons it appears to be a mistake to lead the air-pump suction from the top of the condenser, as shown in Figs. 44 and 45, Plate 51.

An effective way of testing these condensers is to pump air into them, and to brush them over outside with soap and water; bubbles which can be easily observed will then appear wherever even the smallest leakage exists. As however it is almost impossible to prevent leakages from occurring in course of time in long lengths of pipes alternately heated and cooled, it is well not to be sparing in the capacity of the air pump, which in the writer's opinion should be larger than is generally provided for the ordinary surface condenser.

Mr. William George Walker wrote that the tendency referred to in page 186, for a central core of uncondensed steam to pass through the condenser tubes, is due to insufficient internal condensing surface; for steam, like air, requires more cooling surface than water. In experiments with tubes of the Serve pattern, having internal longitudinal vanes or ribs, he found about 25 per cent. more steam per foot run could be condensed than in plain tubes of the same diameter. The best results were obtained with vertical tubes, having their internal surface quite smooth, so that the condensed steam deposited thereon could easily drain off; the presence of a film of condensed steam on the internal surface appears to retard the transfer of heat. Provided economy of space and weight is no object, he thinks it possible to construct an air condenser pure and simple, without the aid of any evaporation of water. In experiments on this point about 2 lbs. of steam were condensed per square foot of surface per hour, with air blown over the surface at a velocity of 1,000 feet per minute: so that about 10 square feet of surface would be required per I.H.P., or about ten times the surface of an ordinary surface condenser. About 2,400 cubic feet of air are required to condense 1 lb. of steam. Therefore 100 H.P. would require about 1,000 square feet of surface and about 80,000 cubic feet of air per minute.

The success of either an evaporative or an air condenser will largely depend upon the proper arrangement of the fan; and in six

(Mr. W. G. Walker.)

of the eight diagrams in Plate 61 the fans are shown forcing or propelling the air into the condenser. Better results are obtained in the writer's experience by suction of the air, so that it is drawn in from all sides through the condenser at a slow velocity to the fan, where it is discharged in a cylindrical column, which should not be baffled or blocked in any manner, but should have a free escape; whereas on the feeding or suction side the air current entering the fan can be baffled to a considerable extent without reducing the efficiency of the fan, providing the air space between the condenser tubes is not reduced too much. An exhausting fan 5 feet diameter, discharging 40,000 cubic feet of air per minute with practically a free inlet and outlet, required 6 H.P. to drive it; for 50,000 cubic feet it required 12 H.P., and for 60,000 cubic feet 22 H.P. When the air was baffled by a resistance equivalent to $\frac{1}{4}$ inch of water gauge beyond what it would encounter with free discharge, the fan required 12 H.P. in order to discharge 40,000 cubic feet per minute; and when the baffling resistance was equivalent to 1 inch of water gauge, it required about 24 H.P. in order to produce the same discharge.

Mr. William Wright wrote that from his own experience in erecting and working evaporative condensers he cannot agree with the opinion expressed in page 186, that it is necessary to stir up the steam in order to condense it more readily. An experiment was tried in this direction by inserting a small tube in the centre of the brass condensing tube, as mentioned in page 186, so as to cause the steam to pass in a thin annular film through the outer tube; but the result was disappointing, and the inner tube had to be removed. The Row indented tube he believes does not overcome the difficulty, but obstructs the passage of the steam inside, and presents awkward recesses outside for scale and dirt to be deposited on, thereby impeding the evaporative power of the tube, while the deposit would also be more difficult to remove than from the plain round smooth surface of a cylindrical tube; moreover the indents must weaken the tube, and render it more liable to collapse under vacuum or burst under pressure. The way in which the test of the

Row tube was carried out, he agrees with Mr. Longridge (page 216), appears not to be quite satisfactory. No contrivance inside or outside of the tubes he thinks can improve their efficiency, which depends simply upon clean surfaces both inside and outside. The Ledward corrugated tube, Fig. 18, Plate 42, instead of obstructing the area of passage, increases the condensing surface both inside and outside, thereby giving more condensing power in the same length of tube. Although he cannot agree that the steam passes in and out of the corrugations (page 187), it certainly passes into them and is condensed there, and so draws into them after it a fresh supply of steam from the current in the tube. These recesses may also be useful for catching oil or grease until their bottom part gets filled, when the oil or grease would flow over as usual. The success of an evaporative condenser is dependent upon clean tube surfaces, clean condensing water, clean air, and freedom from obstructions. Spiral wire coils, wire netting, brass cups, or fibrous material, all require great care and attention in order to maintain a good vacuum; so also do the water distribution, the air supply, and the air pump. The plan of jointing the tubes by expanding their ends in the top boxes, and providing loose glands with rubber washers and water seal in the bottom boxes, is a good one. More ground space and more tube surface are required than is generally supposed, as is shown by the fact that he has never had any difficulty in obtaining a good vacuum with light loads, when the tubes, water, and air have been clean and plentiful.

Mr. Harry Fraser wrote that from his experience the evaporative condenser is a successful and useful apparatus to adopt, if it is not attempted to do too much in too small a space. The oldest form erected of evaporative condensers occupied as much as about 2 square feet of floor space per I.H.P.; whereas in the modern forms with vertical brass tubes attempts have been made to get 15 I.H.P. into this space, and the results have not been so successful. There is not room enough for cleaning the apparatus when it is cramped up in such a small area. If the tubes are made of galvanized wrought-iron 3 inches diameter, and 3 inches clear space is allowed between each

(Mr. Harry Fraser.)
tube, and 18 inches clear space between each alternate row of tubes for cleaning, as is now done in the evaporative condensers largely manufactured by his firm at Millwall, the working of the apparatus is then highly satisfactory. With this arrangement the condensation of 2 I.H.P. is obtained from each square foot of floor space occupied, which is only one quarter of the floor space for the older kinds of evaporative condensers. The air pump should be on the balanced beam principle, and the water-circulating pump should be worked off one of the beams of the air pump, so that there is only one auxiliary engine to look after for the whole working of the condenser. Fans he finds are practically inapplicable, because they would have to be of such large dimensions in order to be of any real value. The evaporative condenser is less costly than a cooling tower, and occupies less floor space, and uses less power; and he anticipates that, when greater experience has been gained with the above form of evaporative condenser, it will be largely adopted. Where condensing has to be done with scant supply of water, there must always be a certain amount of difficulty to be overcome; and the evaporative condenser seems to him to be the most likely arrangement for overcoming this difficulty, when carefully and correctly designed for the work it has to perform.

Mr. Oldham wrote that during the discussion the various kinds of evaporative condensers do not appear to have been sufficiently distinguished one from another. In the paper various proportions of cooling surface are given; but some refer to brass-tube vertical condensers, and others to wrought-iron and cast-iron horizontal condensers. As it is desirable that these should be clearly discriminated, the figures in Table 6 have been collected for greater convenience of comparison, partly from the paper and partly from the writer's experience. With these proportions a vacuum should be maintained of not less than 24 inches of mercury (page 244). The quantity of cooling water in circulation should be :—for condensers with cast-iron tubes and for brass-tube vertical condensers, from ten to fifteen times the weight of the steam condensed per hour; for condensers with horizontal wrought-iron or copper tubes, about five

TABLE 6.—*Weight of Steam Condensed per hour per square foot of condensing surface in various Evaporative Condensers.*

Page	*Condensers with Horizontal Tubes, without Fans.*	Lbs. per hour.
192	Cast-Iron Plain Tubes, Plate 47	1 to $1\frac{1}{2}$
	,, ,, ,, exposed to good steady wind	$1\frac{1}{2}$ to 2
192	Cast-Iron Corrugated Tubes, Ledward, Fig. 18, Plate 42 (* or 8 lbs. per hour per foot run of tube).	*$1\frac{1}{4}$ to $1\frac{1}{2}$*
203	Wrought-Iron Galvanized Tubes, Fraser design .	2 to $2\frac{1}{2}$
	,, ,, or Copper Tubes, in good position on roof	$2\frac{1}{2}$ to 3
	Condensers with Vertical Tubes.	
200	Cast-Iron Plain Tubes, Table 2 and Plate 58 . .	$1\frac{1}{2}$ to 2
	Brass Tubes, without fan and exposed . . .	3 to $3\frac{1}{2}$
	,, ,, with fan at slow speed . . .	4 to 5
	,, ,, with fan at higher speed and good water circulation . .	5 to 6

to ten times the weight of steam condensed per hour. With perfectly clean condensers the quantity of cooling water may be reduced; but the circulating pumps should be made to take the maximum quantity. Although theoretically only one lb. of water should be required for condensing each lb. of steam, yet with so small a quantity it would be impossible to ensure such an even distribution that all the tubes should be covered by the circulating water. The weather also plays an important part in the efficiency of an exposed condenser; on wet or windy days the weight of steam condensed is increased 15 to 20 per cent. The tubes of evaporative condensers are generally found to be clean inside, and with scale on the outside in proportion to the hardness of the water. Clean water should always be used.

So far from the metal of the tubes or their construction having but little to do with the efficiency of the condenser (page 209), the contrary is certainly true, inasmuch as thin wrought-iron or copper tubes are found to be of greater condensing value than thick cast-iron tubes. Moreover the weight of the condenser can be considerably reduced by the employment of either of the former.

(Mr. Oldham.)

It is most important that the exhaust-steam inlets should be so arranged that every tube shall take its equal share of the steam. In some condensers trouble has been caused through the greater part of the steam passing through a few tubes only, while the rest of the tubes remain quite cold; suitable baffles or partitions should therefore be provided for compelling the steam to pass equally through the whole of the tubes.

The condenser mentioned by Mr. Andrews (page 217) has behaved in a peculiarly eccentric fashion, of which it is impossible to offer any explanation without a thorough investigation. These condensers do not usually present such difficulties; and several working on light loads are answering well. In the same instance probably the reason why the fan did not increase the efficiency of the condenser (page 220) was because there was no casing round the condenser; a casing should be fixed round the upper portion of the tubes, so that the air may be drawn in at the lower portion and allowed to pass up amongst them throughout their whole height.

It is highly important that the air pump be kept cool; the supplementary coolers mentioned in the paper are designed for this purpose.

The quantity of cooling water in circulation, mentioned by Mr. Williams (page 234), is erroneous, as will be seen from the proportions already given (page 252). The maximum quantity of water used by the Fraser or the Theisen condenser does not exceed twenty times the weight of steam condensed per hour; and out of this the maximum quantity of water lost by evaporation does not exceed the weight of steam condensed. In the Royle condenser the weights mentioned (page 234) were those used in an experiment.

Unfortunately no correct record has been kept of the value of coal saved, or of the interest on capital &c. (page 244). But from several condensers that are now being erected valuable information will be obtained and recorded, and when made known will probably result in other evaporative condensers being put up.

Other data which have been asked for on particular points have not hitherto been recorded; but on these it is hoped that interesting and trustworthy results will ere long be forthcoming.

FORMAL OPENING OF THE NEW HOUSE.

The formal opening of the New Building in St. James's Park was celebrated by a Conversazione held therein on two successive evenings, 16th and 17th of May, 1899. In addition to all the members of the Institution, invitations were issued to some 750 guests, including representatives of the Government, the Universities, and the Scientific Societies of the country. A pamphlet containing a brief history of the Institution with illustrations of the new house was presented to each of the company; and the contents of the pamphlet with some additions are reproduced here for permanent record.

Brief History of the Institution and Description of the Building.

The objects of the Institution of Mechanical Engineers, which now for the first time occupies a home of its own in London, are to promote the science and practice of Mechanical Engineering in all its branches, and to enable its members to meet and to correspond, thus facilitating the interchange of ideas, and aiding in many ways the interests of the engineering profession.

The Institution, which was founded in 1847, has an honourable history. No one is now living who can state with certainty the precise way in which it originated. According to one version it was the outcome of a gathering of a few engineering friends in the house of Mr. Charles F. Beyer in Cecil Street, Manchester. By no means incompatible with this is the statement of his partner, Mr. Richard Peacock, M.P., who in August 1879 narrated his own recollection of a meeting in 1846 of six gentlemen, of whom he was one, in the house of Mr. James Edward McConnell at the foot of the

Lickey incline on the Bristol and Birmingham Railway, near Bromsgrove. The names of those present were—Mr. Beyer; Mr. Charles Geach, banker, of Birmingham, who became the first treasurer; Mr. McConnell, locomotive superintendent of the Bristol and Birmingham Railway; Mr. Peacock, locomotive superintendent of the Manchester and Sheffield Railway; Mr. George Selby, Smethwick Tube Works, near Birmingham; and Mr. Archibald Slate, who was at that time with Mr. Selby, and became the honorary secretary. It was then and there decided to take steps for the establishment of the Institution, and to issue a circular which is recorded as follows in the first entry in the earliest minute-book kept by the Institution :—

"In the year 1846 the following circular was issued to some of the principal engineers in England.

INSTITUTION OF MECHANICAL ENGINEERS.

To enable Mechanics and Engineers engaged in the different Manufactories, Railways, and other Establishments in the Kingdom, to meet and correspond, and by a mutual interchange of ideas respecting improvements in the various branches of Mechanical Science to increase their knowledge, and give an impulse to inventions likely to be useful to the world.

We hope to have the pleasure of seeing you at a Meeting of the promoters of the above on Wednesday 7th October at 2 p.m. at the Queen's Hotel, Birmingham.

EDWARD HUMPHRYS, Messrs. Rennie's, London.
ARCHIBALD SLATE, Tube Works, Smethwick.
J. E. McCONNELL, Bristol and Birmingham Railway.
CHARLES F. BEYER, Sharp Brothers and Co., Manchester."

In compliance with this invitation a meeting was held on 7th October 1846 at the Queen's Hotel, known also as Bacon's Hotel, which at that time adjoined the former terminus of the London and Birmingham Railway in Curzon Street, Birmingham. The building itself, with its massive stone façade and lofty entrance surmounted by elaborately chiselled embellishments, was utilised ten years later for the offices of the goods department, and still remains as a conspicuous example in Birmingham of the same style of architecture that is seen at Euston. Mr. McConnell occupied the chair; and amongst those present were:—Mr. William Buckle, Soho Works,

Birmingham (James Watt and Co.); Mr. James Brown, Soho (James Watt and Co.); Mr. Charles F. Beyer, Atlas Works, Manchester; Mr. Edward A. Cowper, London Works, Smethwick (Fox and Henderson); Mr. Archibald Slate, Tube Works, Smethwick; Mr. John Edward Clift, Staffordshire and Birmingham Gas Works; Mr. Benjamin Cubitt, New Cross; Mr. Henry Dübs, Warrington (Tayleur's Vulcan Foundry); Mr. Edward Humphrys, Albion Works, London; Mr. William S. Garland, Soho (James Watt and Co.); Mr. Richard Peacock, Manchester and Sheffield Railway; Mr. John Ramsbottom, London and North Western Railway, Longsight, Manchester. The following were appointed a committee to draw up rules for the management of the Institution:—Messrs. Peacock, Slate, Beyer, Humphrys, McConnell, Buckle, Clift, and Cowper.

At the dinner in the evening the toasts included:—Success and prosperity to the Mechanical Engineering Institution, coupled with the name of Mr. Archibald Slate, the honorary secretary of the new Institution; the Institution of Civil Engineers, acknowledged by Mr. Benjamin Cubitt; the Memory of James Watt, responded to by Mr. Buckle; the establishment of Mr. Rennie, for which Mr. Humphrys replied; the Locomotive Manufactories of Great Britain, acknowledged by Mr. Beyer; the liberty of the Press, to which Mr. Maher responded; the health of George Stephenson, the "Father of Railways," and of Mr. Robert Stephenson, the worthy son of a worthy sire; the Railway Directors of Great Britain, acknowledged by Mr. Joseph Sanders, secretary of the Bristol and Birmingham Railway; the health of Mr. Brunel; and the healths of the chairman Mr. McConnell, and the vice-chairman Mr. Buckle.

On Wednesday 18th November 1846, the committee assembled and approved of the rules and regulations for the Institution.

On Wednesday 27th January 1847 a general meeting was held at the Queen's Hotel, Birmingham, for the purpose of forming the Institution. Mr. McConnell, occupying the chair, read a list of gentlemen who had sent answers to a circular inviting their co-operation and their consent to become Members of the Institution. On his proposal, seconded by Mr. Buckle, it was resolved "That the Institution be established, and composed of the gentlemen whose

names he had announced." Mr. Slate having read the Rules of the Institution, which had been prepared by the committee, their adoption was carried, on the motion of Mr. George Stephenson, seconded by Mr. Beyer. Mr. McConnell moved the election of George Stephenson, Esq., as President of the Institution; and the nomination having been seconded by Mr. Cowper was carried with acclamation.

On taking the chair, the President gave an interesting account of his early days at Killingworth Colliery, where his career had commenced. On the motion of Mr. John Henderson, Smethwick (Fox and Henderson), seconded by Mr. Richard Peacock, the following were appointed to be the Vice-Presidents of the Institution:—Joseph Miller, London; Charles F. Beyer, Manchester; James E. McConnell, Wolverton. On the motion of Mr. Peter Rothwell Jackson, seconded by Mr. James Ward Hoby, the following were appointed to be the Council of the Institution:—Edward Humphrys, London; Benjamin Fothergill, Manchester; Joseph Radford, Manchester; William Buckle, Soho; Edward A. Cowper, Smethwick. On the motion of Mr. Buckle, seconded by Mr. McConnell, it was resolved that Mr. Charles Geach, of the Midland Bank, Birmingham, be Treasurer to the Institution. On the motion of Mr. Beyer, seconded by Mr. Henry Chapman, it was resolved that Mr. Slate be Secretary and Mr. Maher acting secretary to the Institution. Of the original Members who joined in constituting the Institution on 27th January 1847 the only survivor is now Mr. Richard Williams of Wednesbury.

The first meeting of the Institution for the reading of papers took place on 28th April 1847, and like the first general meeting it was held at the Queen's Hotel, Birmingham. The meetings were continued at the Queen's Hotel, then in Temple Buildings, New Street, and in the Philosophical Institution, Cannon Street, Birmingham, until 1850, when premises were acquired in Newhall Street, which formed the head-quarters of the Institution for the next twenty-seven years. After 1864 the meetings were held in the Midland Institute until 1877, when the head-quarters of the Institution were transferred to London, suitable accommodation for the staff

and the library being obtained at 19 Victoria Street, Westminster; and by the courtesy of the Institution of Civil Engineers, the London meetings were held in the hall of that Institution. These arrangements continued in force until the current year, when, as already stated, the Institution of Mechanical Engineers entered into the possession of a new home of its own, which it is the object of this notice to describe.

Before giving this description however, something more may be said as to the growth of the Institution. The proposal to hold the Summer Meetings of the Institution in the leading centres of engineering throughout the kingdom originated in 1856 with Mr. James Fenton, who was consulting engineer to the Low Moor Iron Co. from 1851 to 1863, and was at that time a member of the Council; and through his energetic exertions the proposal was realised in September of the same year, by a meeting held for the first time in Glasgow, under the presidency of Mr. Joseph Whitworth. As one result of this new step, the number of Members of the Institution, which for the seven preceding years had remained at almost a dead level of little over two hundred, now began at once to increase at a rate of growth which has since continued to progress steadily up to the present date, as shown by the table on the next page and plotted in the diagrams in Plates 69 and 70. This meeting in Glasgow showed the engineers of the neighbourhood their own numerical strength; and led to the establishment in the following year of the Institution of Engineers and Shipbuilders in Scotland, under the presidency of Professor W. J. Macquorn Rankine. The establishment of that Institution, and subsequently of various other engineering societies in different districts, is believed to have proved ultimately beneficial to the growth and prosperity of the Institution of Mechanical Engineers. Summer meetings have been held at the following places during the last forty-three years:—Glasgow four times, Manchester four times; Newcastle, Leeds, Birmingham, Liverpool, and Paris, each three times; Sheffield, London, Dublin, Middlesbrough, and Cardiff, each twice; and once each in Nottingham, Penzance, Bristol, Barrow-in-Furness, Liége, Lincoln, Edinburgh, Portsmouth, Belfast, and Derby. In connection with the meeting at Portsmouth in 1892 the Council drew the attention of the

Year.	Number of Members.	Annual Income. £	Invested Capital. £	Members and Visitors attending Meetings in the year. Members.	Visitors.	Total.
1847	107	515				
1848	189	741				
1849	201	600				
1850	202	676				
1851	203	619				
1852	204	614				
1853	216	703				
1854	228	702				
1855	218	620				
Commencement of peripatetic Summer Meetings in 1856.						
1856	250	817				
1857	301	997				
1858	341	1,097				
1859	391	1.275				
1860	428	1,445				
1861	464	1,391				
1862	497	1,618				
1863	540	1,889				
1864	572	1,926				
1865	652	2,141				
1866	728	2,462				
1867	791	2,388				
1868	825	2,357	4,500			
1869	855	2,650	4,500			
1870	862	2,823	4,500			
1871	875	2,806	5,973			
1872	912	2,953	6,973			
1873	956	3,208	7,978			
1874	992	3,270	9,178	416	231	647
1875	1,018	3,471	10,188	434	203	637
1876	1,041	3,440	11,016	357	117	474
1877	1,075	3,641	11,869	521	168	689
Removal from Birmingham to London in 1877.						
1878	1,140	3,801	8,868	394	263	657
1879	1,178	3,782	8,868	441	314	755
1880	1,210	4,085	8,868	414	269	683
1881	1,276	4,248	9,217	485	279	764
1882	1,370	4,660	9,617	509	270	779
1883	1,440	4,690	10,617	397	189	586
1884	1,554	5,094	10,617	887	248	1,135
1885	1,640	5,330	11,967	607	362	969
1886	1,674	5,701	13,467	620	370	990
1887	1,741	5,753	15,469	554	260	814
1888	1,806	6,121	16,490	442	244	686
1889	1,858	6,260	17,489	418	246	664
1890	1,943	6,784	18,888	518	236	754
1891	2,077	7,212	20,287	628	273	901
1892	2,147	7,192	22,537	502	299	801
1893	2,157	7,030	24,787	426	265	691
1894	2,222	7,081	26,558	620	331	951
1895	2,271	7,274	27,340	546	363	909
1896	2,360	7,388	*34,979	488	334	822
1897	2,490	7,906	†37,619	677	308	985
1898	2,680	8,496	‡37,947	910	331	1,241

* Capital, 1896 { Invested £18,102; House £16,877 } = £34,979.

† Capital, 1897 { Invested £32,183; House £30,436 } Less Debentures £25,000 = £37,619.

‡ Capital, 1898 { Invested £15,403; House £47,544 } Less Debentures £25,000 = £37,947.

Members to a feature which had been noted with much gratification, namely that the cost of the necessary arrangements was distributed among the Members for whose benefit they were made: thereby showing for the first time how the Members may be enabled to enjoy the advantage of meeting in various localities, free from all misgivings of their visit assuming in any degree the aspect of a visitation. The same considerations clearly enlarge the range of localities in which future meetings of the Institution may advantageously be held.

A highly important branch of the work of the Institution has been that of the Research Committees, whose duty it is to investigate and report upon certain selected questions relating to mechanical engineering, which cannot well be adequately treated in the course of ordinary practice. Amongst the subjects thus taken up are the strength of riveted joints, the hardening and tempering of steel, friction at high velocities, marine-engine trials, the value of the steam-jacket, gas engines, and the properties of alloys. The first Research Committee was appointed in 1879, and since that date upwards of £4,000 has been spent in experimental research by the Institution; while the value of the personal work which has been performed—in all cases gratuitously—by the numerous members who have constituted the various research committees must be placed at a vastly larger sum.

The Institution at present possesses a library of about 10,000 volumes; and now that ample accommodation has been secured for its extension, it is hoped that this number may be rapidly increased. The Proceedings of the Institution fill over 50 volumes; Transactions are exchanged with 103 societies, 47 inland and 56 foreign; and 53 volumes are presented annually to 26 colleges and libraries.

The new house of the Institution has been erected on a unique site. The façade overlooks a Royal Park, with a magnificent view over the Horse Guards' Parade and the ornamental waters of St. James's Park. Around are to be seen the more ornate of the Government Offices—the Foreign Office, the Office of Works, and the new Admiralty Buildings.

The following description of the building has been prepared by the architect, Mr. Basil Slade :—

"The house has been about two years in building, and stands on a gravel foundation in running water about 22 feet below the ground level. Some trouble was experienced in laying the concrete foundation, as the effect of the tides in the Thames was appreciably felt; pulsometer pumps were used, and massive walls of concrete, 7 feet wide, were put in, these walls being traversed by strong terra-cotta pipes to permit of the easy flow of water from the centre of the building.

"The basement floor of the house is practically an asphalt-lined tank resting on the top of concrete legs. The building is perfectly dry, and no settlement cracks have been as yet perceived, nor are any anticipated.

"The building has been designed to suit the increasing scientific and literary requirements of the Institution and its official staff.

"Entering the house from Birdcage Walk, which is a continuation of Great George Street, Westminster — the home of kindred Institutions—the entrance door is sheltered by a lofty Portland stone portico supported by Ionic columns. To the left is a bold tower, in which the staircase and lift rise to the upper floors. The exterior façade is of renaissance treatment in Portland stone and red brick.

"The entrance hall and staircase are treated with Hungarian oak panellings, floorings, arcadings, balusters, newels, &c., French polished, and surmounted by plain Persian red walls and enriched ceilings.

"Immediately opposite the entrance is the main doorway into the lecture theatre. This room has a Georgian ceiling with central glass dome, from which it is lighted by day, and by night from a cluster of incandescent electric hanging lamps. The floor is constructed of movable platforms, which can be arranged to form terraces or a level floor, as desired. The ornamental ceiling is hung from the top and free from the walls, and has a bold cove, behind which the wall-diagram rollers are hidden. It is trusted this arrangement of ceiling will give good acoustic results, and prevent any echo.

"On this floor, and approached by a broad corridor, is the council chamber, a room treated with a more Jacobean freedom, with an oaken ribbed star-pattern ceiling and bold cove to the cornice.

"On the entresol floor below is found the marble tea room or withdrawing room, running under the full length of the entrance hall. This room has been lined and decorated with costly marbles throughout; floors, walls, arcadings, and access staircases have been treated with both new and rare stones. The treatment is of latter date, in style following the Italian. The pilasters are of antique sienna with statuary white caps and bases; the surbase is of dark dove with dado of cippolino and verte antique plinth. The panels are picked Mexican onyx, arranged to show the veining to best advantage, with delicate outline or border of pale dove with pavonazzi ground; the whole surmounted with a light statuary moulding and cippolino frieze. The ceiling is kept simple in design, with a few lines of gold to enhance the contrast of the richly coloured walls. The flooring is of piastraccia and dark grande antique squares. The tea room is served by a kitchen and pantry adjoining.

"On the same floor is to be found the principal lavatory, also treated in marbles, teaks, &c.

"The space under the lecture hall is occupied by two floors of extensive area with annexes for the storage of 'Proceedings' and other papers, amply large enough to provide accommodation for many years to come.

"On the basement floor are to be found the boiler room, ventilation ducts, and general electrical mechanical accessories.

"Re-ascending the stairs, above the entrance hall is the reading and smoking room—a room all in white of a simple Georgian character. On the same floor are the secretarial offices and galleries of the lecture hall.

"The fine and light hand-wrought ironwork to the staircase and lift shaft deserves special notice.

"The whole of the floor above is occupied with the library—a lofty apartment with annexes and book-galleries. A bold cove and pendentive ceiling is brought forward over the book-cases, giving the appearance of the books being recessed in the walls. The library is treated in the Elizabethan style, Hungarian picked oak being used throughout. The galleries are supported by bold cantilever oak modillions and Ionic columns and caps standing on a table-height

shelf. Bastard statuary pilasters and oaken impost and arcades separate the main library from the annexes.

"The remainder of the building is occupied with offices for the staff, a room for the meetings of Graduates, spacious drawing and diagram rooms, and apartments for the housekeeper.

"The building is lit throughout with electricity; and the same agent is used for working the lifts, clocks, ventilation fans, and power for the exhibition of models in the theatre.

"The principal rooms are ventilated on the plenum system. The fresh air is drawn in by an electrically-driven fan, 4 feet diameter, from the north area in the park, and cleansed over fibre screens automatically washed with water, then passed over a radiation coil and along a duct up to the various apartments, whence the vitiated air is forced up vents to the top of the building."

The acquisition of the site and the erection and equipment of the house have been carried out under the supervision of the Presidents holding office since 1891, and of a House Committee consisting of Members of Council, who have devoted a great amount of time and trouble to the work.

The present notice is accompanied by a series of plans and perspective views which will give an excellent idea of the character of the building.

MEMOIRS.

William Carpmael was born in London on 1st December 1832, and was educated at Clapham Grammar School under Rev. Charles Pritchard, who afterwards became Savilian professor of astronomy at the University of Oxford. In 1850 he entered the office of Messrs. Carpmael and Co., patent agents; and thenceforth till within a short time of his death he devoted the whole of his time to the practice of his profession. On the death of his father in 1867 (Proceedings 1868, page 14) he became senior partner in the firm. Taking always a great interest in questions relating to patent law and practice, he gave evidence in 1872 before a select committee of the House of Commons on patent law; and in 1883 he took part in a deputation to the then President of the Board of Trade, with the result that material alterations were made in the patent act at that time under consideration, which afterwards became law. He also took a keen interest in the status of the profession, and was one of the founders of the Institute of Patent Agents. From its foundation in 1882 he was a member of the Council, and he was elected President in 1886 and 1887. When the Institute was incorporated by royal charter in 1891, he remained a member of the Council. He contributed to the transactions numerous papers on professional subjects. For some years his health had been failing, and he was finally compelled to retire from practice. He died on 29th May 1899 at the age of sixty-six. He became a Member of this Institution in 1866.

James Charnock was born on 18th March 1851 at Dukinfield, near Manchester. He received his education from 1857 to 1868 at St. John's Schools, Dukinfield, and in the science and art classes of the Stalybridge Mechanics' Institute while learning his trade at

Messrs. Sidebottoms, cotton spinners, of Stalybridge, who occasionally made their own machinery. In 1868, at the early age of sixteen and on the recommendation of Messrs. Platt Brothers of Oldham, he went to Russia, being engaged by Messrs. De Jersey and Co. of Manchester to superintend the erection and working of special machinery in cotton mills, when the industry was in its infancy in that country. With this firm he made successive contracts up to 1879, all at the Kranholm mills of Messrs. L. Knoop, at Narva, Esthonia, then as now the largest cotton spinning and manufacturing mills in the world. In 1879 he became manager of the Ismailova mills near Moscow. In 1881 he was engaged to build and manage new mills at Nicholski near Moscow for Messrs. Vicoul, Morosoff and Sons, then a small weaving and dyeing firm. Under his management, embracing as it did the construction of the mills, the housing and provisioning of the workpeople, and the supervision of forests and turf fields, the concern developed rapidly, until at the present time it is one of the most successful in Russia and one of the largest in the world, employing nearly 12,000 hands in cotton spinning, weaving, dyeing, and finishing, and in forestry. From 1883 he was a partner in the firm, who now house some 22,000 persons—men, women, and children—besides providing for the lodging of another 9,000 round the district. He was also one of the original founders and a director of the Savina Vigogne cotton spinning and weaving mills of Messrs. Vicoul, Morosoff, Ivan Poliakoff and Co., employing about 3,000 workpeople. For the recovery of his health, which had suffered from overwork, he had made a journey to the Mediterranean, but without deriving much benefit therefrom; and was on his way to London, when he succumbed to acute peritonitis in Moscow, where he died on 16–28th May 1899 at the age of forty-eight. He had served his firm for some eighteen years, and was recognised as one of the principal authorities on the cotton trade in Russia. He became a Member of this Institution in 1895.

Captain HENRY FRANCIS GAYNOR was born in 1864. He received his education from 1878 to 1882 at the Royal Naval School,

New Cross; from 1882 to 1884 at the Royal Military Academy, Woolwich; and from 1884 to 1886 at the School of Military Engineering, Chatham. His studies were specially directed to mechanical engineering, and in 1884 he received his commission in the Royal Engineers. During four months in 1886 he was engaged in superintending screw-pile driving at the Royal Arsenal, Woolwich; and then spent one year 1886–87 in the Elswick Works of Sir W. G. Armstrong, Mitchell, and Co., where his time was divided between the foundry, fitting shop, smiths' shop, and ordnance drawing office. From 1887 to 1890 he was posted to the 8th (Railway) Company of Royal Engineers, Chatham. In 1890 he was sent to Singapore, where he remained till 1893 in charge of the erection of gun emplacements and pivots for 10-inch breech-loading guns; and was also appointed inspecting officer of machinery. From 1893 to 1898 he was on the instructional staff of the School of Military Engineering, Chatham, to instruct in steam engineering; and was appointed also to take charge of the Royal Engineer workshops at Chatham, including foundry, fitting, smiths', machine, pattern-makers', and wheelers' shops. On leaving this position he passed for the Staff College, Camberley, in August 1898. His death took place on 27th June 1899 at the age of thirty-five, from an accident on the previous day, when his horse bolted and threw him against a tree. For some years past he had devoted much time to the invention of an automatic sight, in which the means of correcting for rise and fall of tide were both ingenious and practical. He became a Member of this Institution in 1895.

Manassah Gledhill was born at Huddersfield on 15th December 1826. As a youth he developed a strong natural taste for mechanics and engineering, and studied closely to instruct himself in the various branches. He served his time with Messrs. Parr, Curtis, and Madeley, engineers and machinists, Manchester; and after working in one or two other shops he obtained employment in September 1852 as a turner in the works of Sir Joseph then Mr. Whitworth in Chorlton Street, Manchester. Mr. Whitworth was at that time engaged in developing his plan of hexagonal rifling

for the bore of heavy cannon; and the first gun on that principle Mr. Gledhill succeeded in satisfactorily rifling in the lathe himself, which in those days was a feat of considerable skill and difficulty, and was personally acknowledged by Mr. Whitworth. In October 1858 he was appointed foreman, and in 1863 was made works manager of the gun, ordnance, and steel departments, being associated with Sir J. Whitworth's early experiments in artillery at Shoeburyness and Southport; and was engaged on working out the flat-headed shot which penetrated a 4-inch wrought-iron armour-plate attached to the side of the "Alfred." The shot was fired from a 68-pounder cast-iron gun rifled on the Whitworth hexagonal plan, and was driven through the plate and entered the planking of the ship's side. This was the first instance of the penetration of a 4-inch armour-plate by solid shot, and from it dates the use of steel projectiles for that purpose. He had also much to do with the development of the fluid-compressed casting process for steel ingots, whereby steel is still largely manufactured by the firm. His most important work was the origination of the hydraulic forging press for forging heavy steel ingots, which forms one of the most valuable modern developments in engineering. His perfecting of the hydraulic forging press revolutionized the manufacture of large ordnance and marine forgings, which previously it had not been possible to make by steam hammers. Owing to the comparative ease with which large gun tubes and forgings can be produced and supplied by the press, the designs of heavy guns have in recent years undergone a complete change; they are now made in a minimum number of forgings, thereby greatly increasing the strength of the gun in all directions. He had also devised many improvements in presses, guns, projectiles, marine shafting, and various machinery; and a hydraulic forging press of 12,000 tons pressure, the largest yet made, was nearing completion at the time of his death. From November 1880 he was managing director of Sir Joseph Whitworth and Co. The removal of their works from Chorlton Street to their present site at Openshaw near Manchester was carried out largely under his supervision in 1880. In 1896, when the amalgamation of the firm with that of Sir W. G. Armstrong, Mitchell, and Co.

took place, he became a director of the joint concern, and retained his position as managing director of the Openshaw works, though failing health abated his active part in the administration. His death took place at his residence, Birchfield, Rusholme, Manchester, on 13th September 1898, in the seventy-second year of his age. He was a justice of the peace for the county of Lancaster. He became a Member of this Institution in 1887.

John Hawthorn Kitson was born at Leeds on 17th May 1843, being the third son of Mr. James Kitson, senior partner in the firm of Kitson, Thompson, and Hewitson, Airedale Foundry, Leeds. He received his second name after his father's friend, Mr. Robert Hawthorn (Proceedings 1868, page 15). After being educated at University College School, London, and graduating B.A. in 1863 at the University of London, he entered the Airedale Foundry, and worked through the various departments; and in 1866 became partner with his father, upon whose retirement in 1876 he was joined in the re-construction of the firm by his brother, now Sir James Kitson, Bart., by Mr. Thomas Purvis Reay, and later by his nephew, Mr. E. Kitson Clark. For thirty-six years he applied himself exclusively to the management of the engine works; and during this period he was actively concerned in the consideration of the design and material suitable for nearly all classes of locomotive engines, burning all kinds of fuel, and under all conditions of climate and permanent way. Possessing a remarkable memory, he was able to recall with accuracy details of locomotive design and dimensions, and incidents of locomotive history; and thus would attractively illustrate his intimate acquaintance with the construction and development of the locomotive engine. In the formation of the engineering employers' federation in 1897 he took an active part, and was chairman of the Leeds section; and was also a member of the emergency committee. He became a Member of this Institution in 1868, and was a Member of Council from 1880 to 1884. In 1875 he became a Member of the Institution of Civil Engineers. Having long suffered much from rheumatism, he died at his residence, Elmet Hall, near Leeds, on 21st May 1899, at the age of fifty-six.

HENRY MAUDSLAY was born in Lambeth on 15th June 1822, being the eldest son of Mr. Thomas Henry Maudslay, engineer, and grandson of Henry Maudslay, the celebrated mechanical engineer, who died in 1831 and was buried in Woolwich churchyard. In his early connection with his father's firm, Messrs. Maudslay, Sons, and Field, he was employed in setting up machinery in Paris for a government tobacco manufactory; and subsequently in the same work in Portugal. In connection with the latter he was created by the King of Portugal a Chevalier of the Order of Christ, in recognition of his personal services. Afterwards he was engaged upon work connected with docks at Malta, before that department had been taken over by the government. Otherwise his professional career was confined to the superintendence of the works at Lambeth, and to trial trips of steamers. Subsequently he spent much time in Palestine, and at his own expense carried out some important excavations in Jerusalem, besides rendering much assistance to the Palestine exploration fund. A large portion of a paving which he discovered in Jerusalem he presented to St. Paul's Cathedral; and another portion to Freemasons' Hall. His death took place in Westminster on 18th July 1899 at the age of seventy-seven. He became a Member of this Institution in 1853, and was a Member of Council in 1855–6, and a Vice-President from 1857 to 1867. During these years he took an active part in the discussions at the meetings, at which he frequently occupied the chair. He was also for fifty years a Member of the Institution of Civil Engineers.

HENRY SIMON was born in Brieg, Silesia, on 7th June 1835, his father being a business man, a county magistrate, and a director of one of the earliest German railways, and his mother an authoress of some distinction. His uncle, Heinrich Simon, having as a leading member of the Prussian parliament taken a prominent part in the revolution of 1848, was compelled to leave Brieg, and was followed by his nephew to Zurich, where the latter attended the cantonal public school. In 1854, at the age of nineteen, he entered the University of Breslau; and subsequently returning to Switzerland studied engineering at the Swiss Federal Technical College, Zurich,

where he obtained the engineering degree in 1859. He then went to Berlin, to go through his period of military service, first in the artillery, and afterwards in the guards. On the completion of this duty, he was engaged as a draughtsman by Messrs. Rohrig, Rohrig, and König at Magdeburg, who were manufacturers of water motors, turbines, and machinery for sugar works. In 1860 he came to England, and was appointed resident engineer for railway contracts in Russia by Messrs. Jametel of Manchester, for whom he spent the greater part of 1861–2 in Russia on the railway between Warsaw and Wilna, superintending the execution of various works for a distance of about 300 miles. During 1863–4 he made business journeys in Italy and France. Coming to England again, he established himself as a consulting engineer in Manchester, where he became naturalized as a British subject. Nearly the whole of 1867 he spent in Paris in connection with the English section of the International Exhibition of that year. Subsequently he was actively engaged in the supply of locomotives, rails, wheels and axles, and other material to Austrian, Rhenish, and other continental railways. His mechanical training early led him to realize the defects of the old process of flour milling; and he took up in its infancy the plan of roller milling now adopted in nearly all civilised countries, whereby the production of flour has been cheapened and increased. Although originally no better clue was placed in his hands than a crude three-high roller-mill, which performed to advantage some of the work previously done by stones, he was fully convinced thereby that the principle underlying the use of rollers would revolutionize the milling industry; and for many years almost all his energy was devoted to the development and application of this principle. From 1879 to 1897 he took out nearly thirty patents, dealing principally with the three most important processes in flour milling, namely grinding, purifying, and dressing; and also with the method of cleaning wheat in preparation for grinding, by washing and drying it. The last constituted an epoch in flour milling, and the advantages thereby gained were equal in importance to those resulting from the substitution of rollers in place of stones. On the subject of roller milling he contributed a paper to the Institution of Civil Engineers

in 1882 (Proceedings, vol. lxx, page 191), and another to this Institution in 1889 (Proceedings, page 148). The first complete roller-mill which he fitted up in England without the use of stones was for Mr. Arthur McDougall of Manchester in 1878, and in Ireland for Messrs. E. Shackleton and Sons of Carlow in 1879; the first automatic roller flour mill in England was for Messrs. F. A. Frost and Sons of Chester in 1881. These were soon followed by larger mills in Leeds, London, Leith, Hull, York, and elsewhere; and by the largest of all in Rio de Janeiro, which formed the special subject of his paper in 1889. He also introduced with much success the Simon-Carvès coke ovens, by which the loss of ammonia and tar by-products is saved, as well as the loss entailed in vegetation destroyed upon the land that was laid waste by the sulphurous smoke emitted from the short chimneys of the ordinary coke ovens; the plan was first carried out on a large scale in 1882 at the extensive collieries of Messrs. Pease and Partners in the county of Durham, and has since been adopted in many other places. Other inventions which he improved and introduced into this country were the Chaudron method of sinking shafts, the Lehmann hot-air engine, and the Galland plan of pneumatic malting. He was the prime mover in the erection of the Manchester Crematorium (Proceedings 1894, page 438), of which he was the chairman; his design of the furnace there employed has since been adopted for the municipal crematorium at Shanghai, and also for that at Hull. He was the first chairman of the Manchester Labourers' Dwellings; and more recently was one of the originators of the Manchester Pure Milk Supply. In 1895 he endowed the Henry Simon professorship of German literature in Owens College, Manchester, besides contributing munificently to the establishment of a new laboratory there. He became a Member of this Institution in 1871, and was also a Member of the Austrian Society of Engineers and Architects, and of the French Society of Civil Engineers. His death took place at his residence at Didsbury, Manchester, on 22nd July 1899, at the age of sixty-four.

INDEX.

1899.

Parts 1–2.

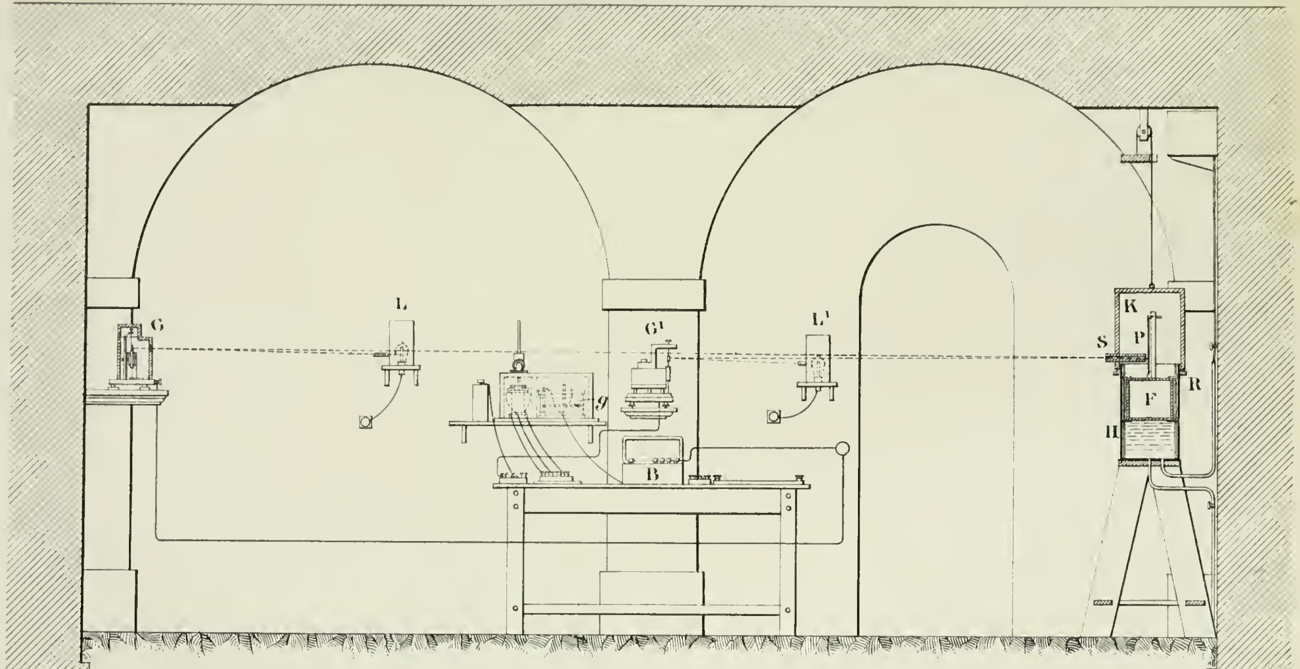
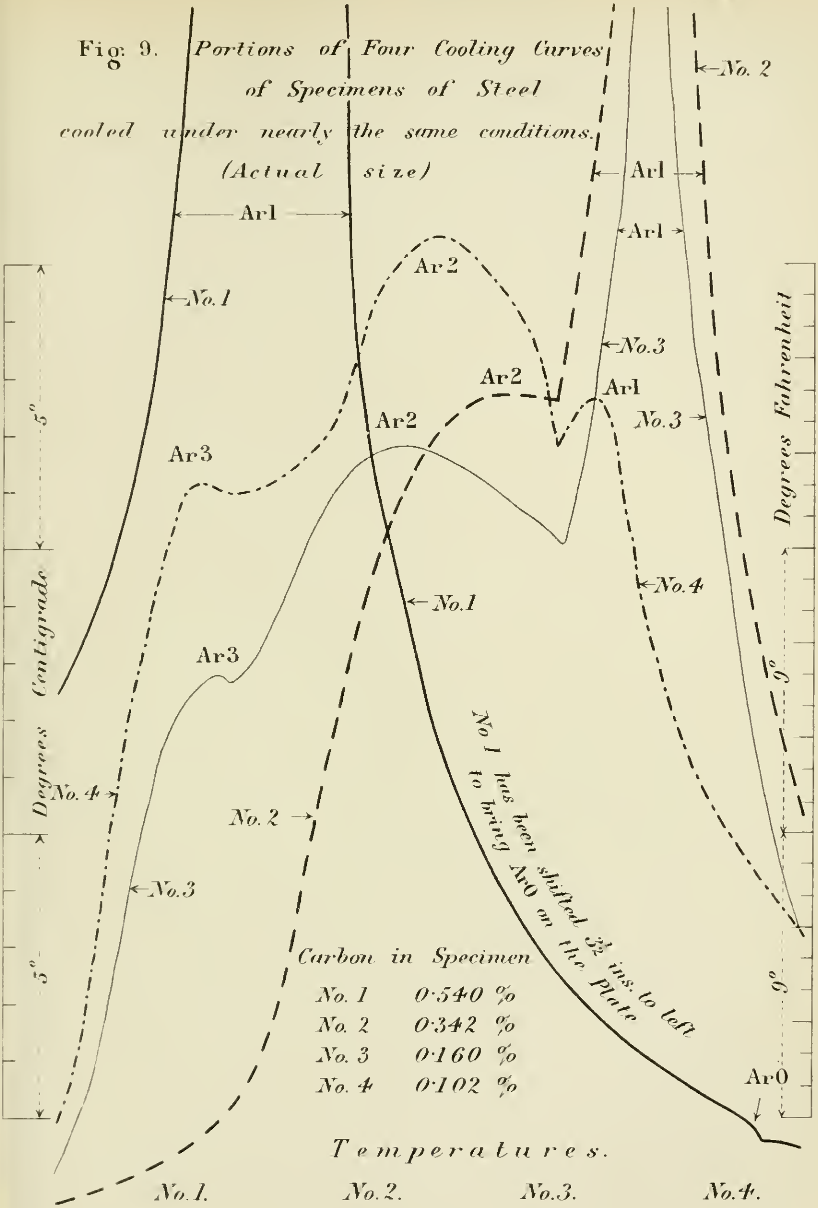


Fig. 7. *General Arrangement of the Recording Apparatus at the Royal Mint.*

Inches 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet

Plate 1.

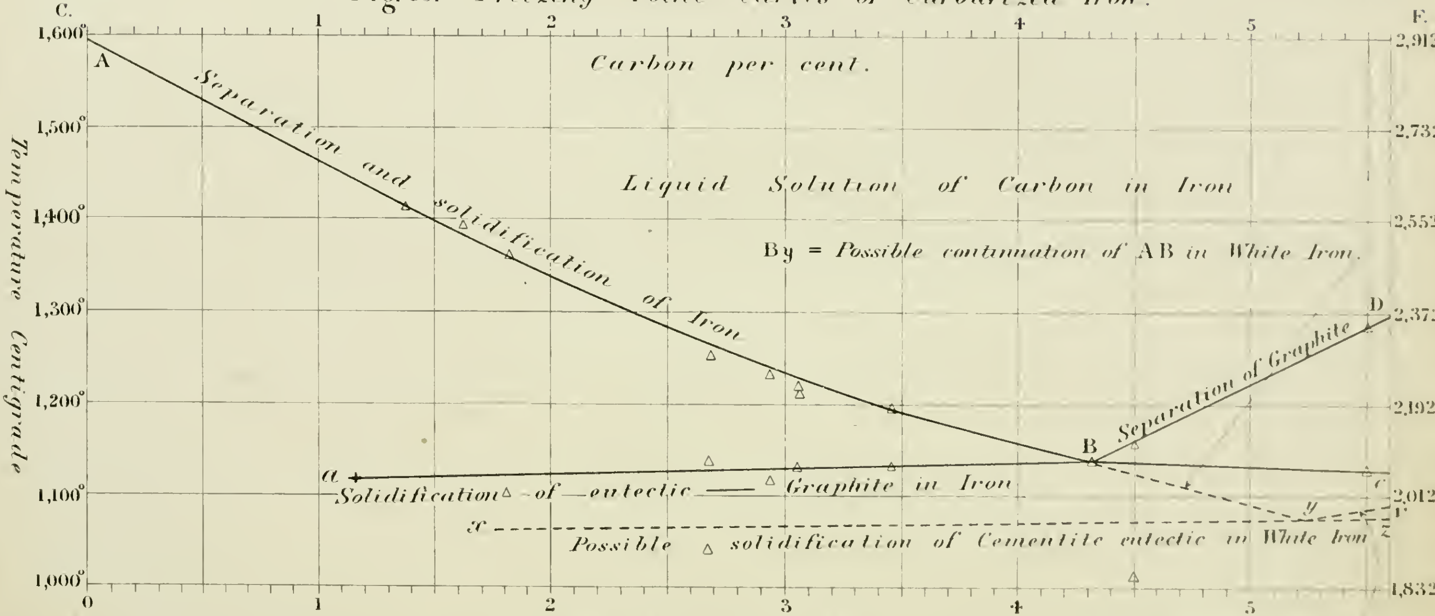
Fig. 9. *Portions of Four Cooling Curves of Specimens of Steel cooled under nearly the same conditions. (Actual size)*



Temperatures.

	No. 1. C.	*No. 1.* F.	*No. 2.* C.	*No. 2.* F.	*No. 3.* C.	*No. 3.* F.	*No. 4.* C.	*No. 4.* F.
Ar0	580°	= 1,076°	—	—	—	—	—	—
Ar1	690°	= 1,274°	690°	= 1,274°	690°	= 1,274°	690°	= 1,274°
Ar2	733°	= 1,351°	767°	= 1,412°	767°	= 1,412°	767°	= 1,412°
Ar3	—	—	—	—	838°	= 1,540°	862°	= 1,583°

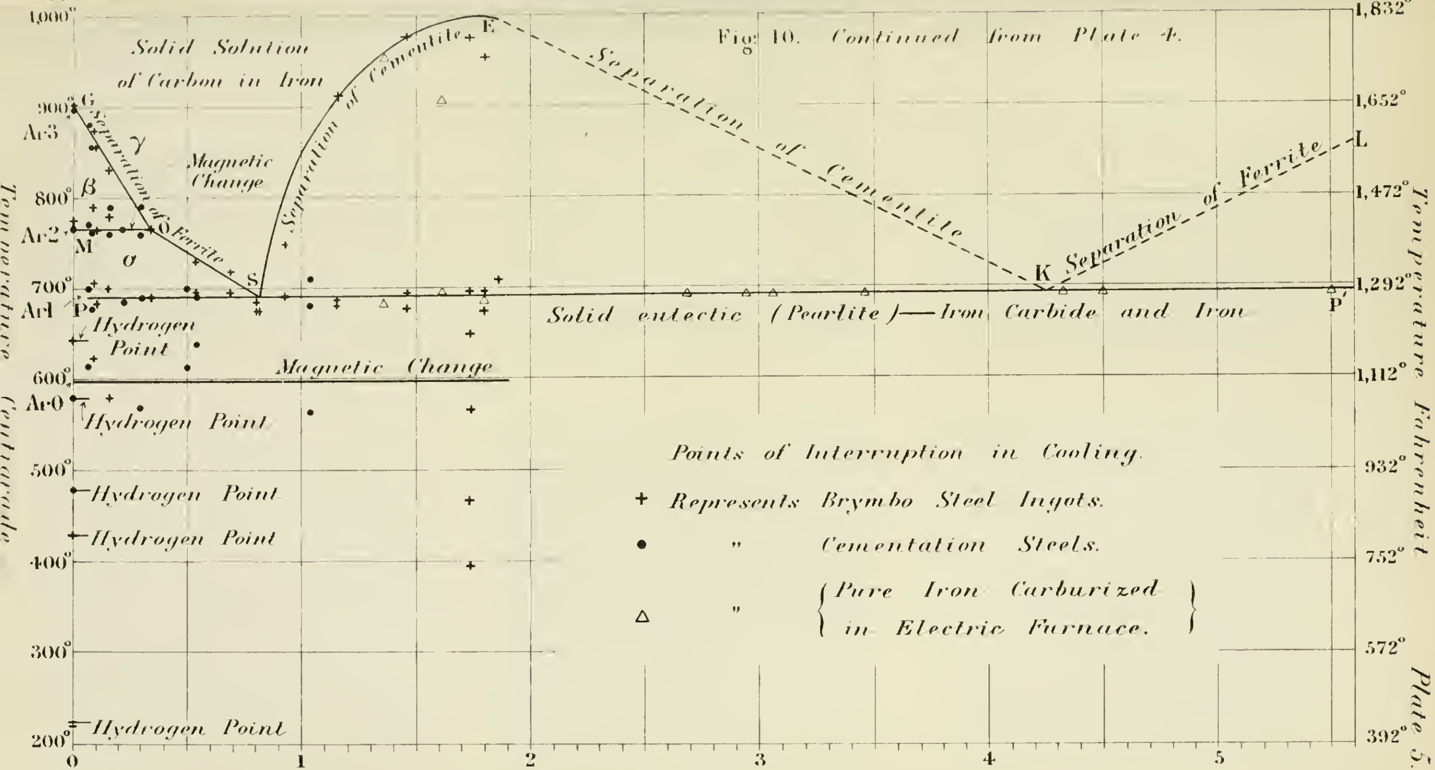
Fig. 10. *Freezing-Point Curves of Carburized Iron.*



yv = Possible separation of Cementite in fused White Iron.

Mechanical Engineers 1899.

See continuation in Plate 5.

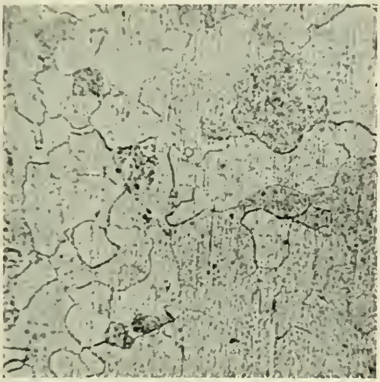


Mechanical Engineers 1899.

Typical Photo-Micrographs of Slowly Cooled Iron and Steel.

Fig. 11. × *140 diams.* Fig. 12. × *850 diams.*

Iron containing 0·05% Carbon.



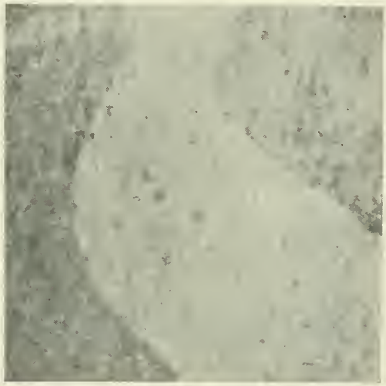
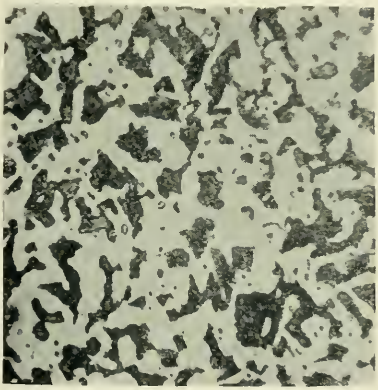


Fig. 13. *Rail Steel.*
0·33 C. 0·69 Mn. × *140 diams.*

Fig. 14. *Rail Steel.*
0·36 C. 1·009 Mn. × *140 diams.*



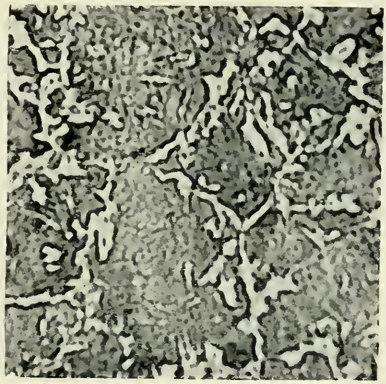
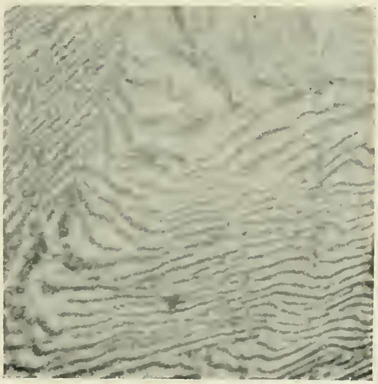
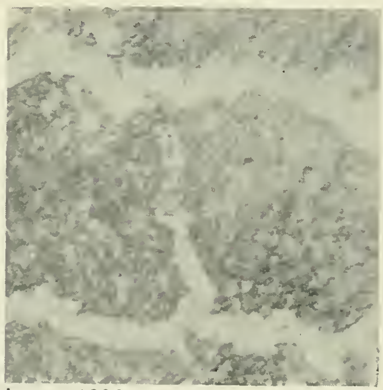


Fig. 15. *Pearlite.*
0·82 C. very little Mn. × *850 diams.*

Fig. 16. *Cementite and Pearlite.*
1·4 C. × *850 diams.*





Typical Photo-Micrographs of Steel.

Fig. 17. *Slag Flaw in Rail.*
0·27 C. 0·71 Mn. × 640 diams.

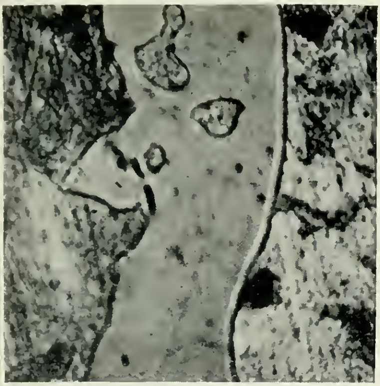


Fig. 18. *Troostite, Martensite, & Ferrite.*
0·54 C. × 850 diams.

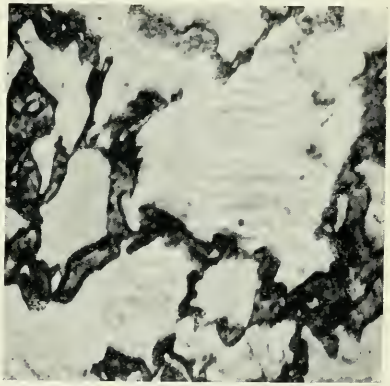


Fig. 19. *Quenched in Water.*
0·54 C. Martensite × 850 diams.

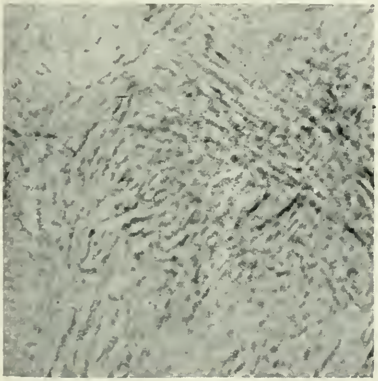


Fig. 20. *Tempered Structure.*
0·54 C. × 850 diams.

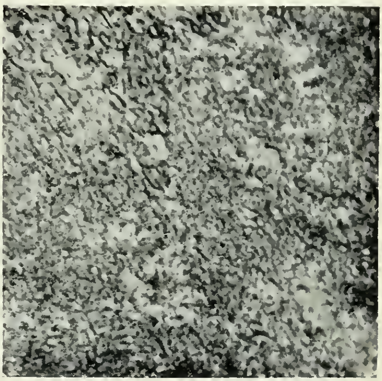


Fig. 21. *× 60 diams.*

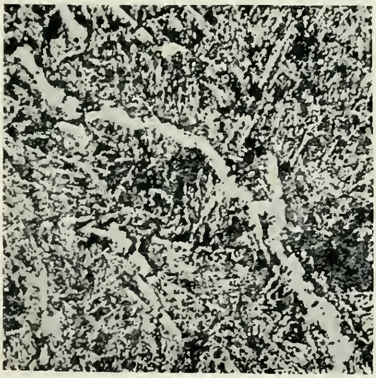
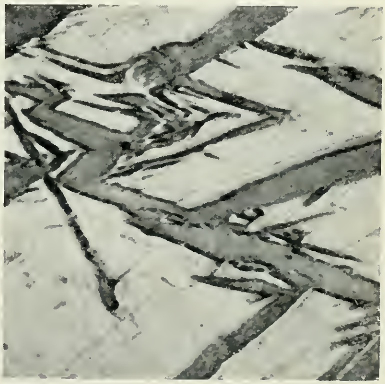


Fig. 22. *× 850 diams.*

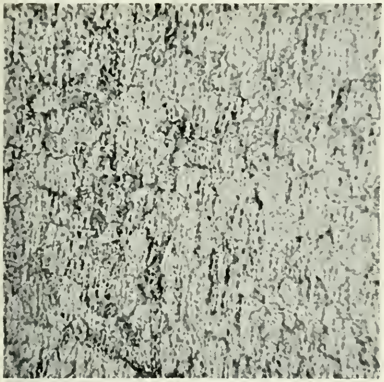


Austenite and Martensite. 1·8 C.

Slowly Cooled Steels.

Fig. 23. × *140 diams.* Fig. 24. × *850 diams.*

Cementation 1.A. 0·07 C.



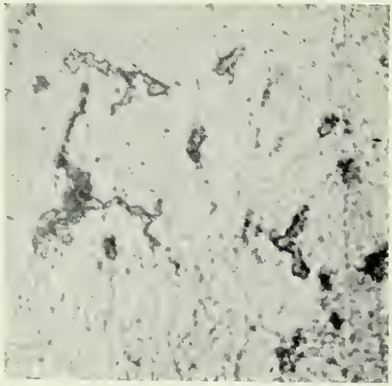


Fig. 25. × *140 diams.* Fig. 26. × *850 diams.*

Brymbo No. 21. 0·097 C.

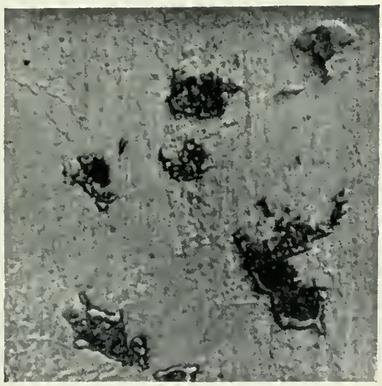
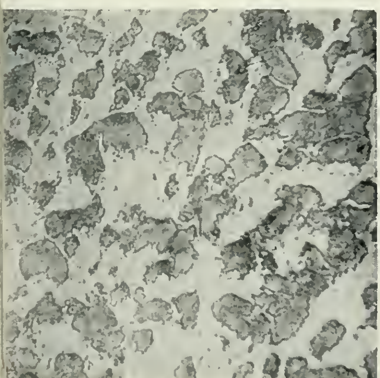


Fig. 27. × *140 diams.* Fig. 28. × *850 diams*

Cementation A.A. 0·218 C.



Slowly Cooled Steels.

Fig. 29. × *140 diams.* Fig. 30. × *850 diams.*

Cementation 1.C. 0·300 C.

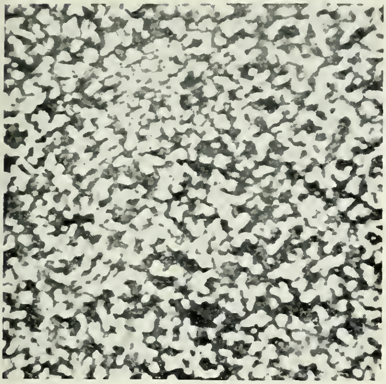
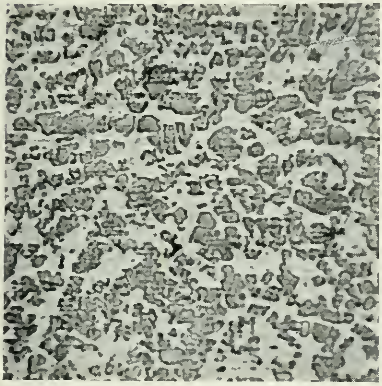


Fig. 31. × *140 diams.* Fig. 32. × *850 diams.*

Brymbo No. 14. 0·342 C.



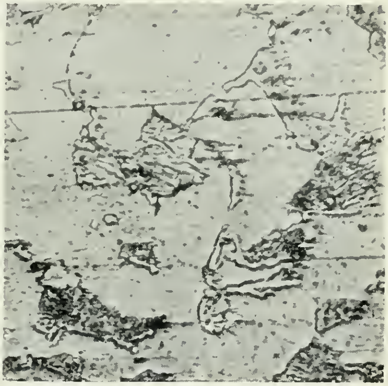
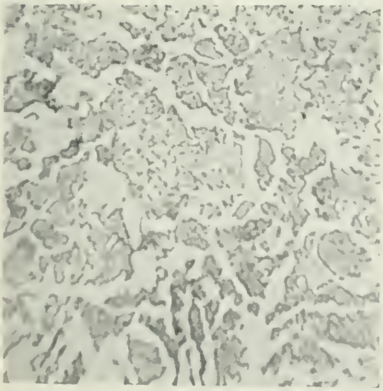
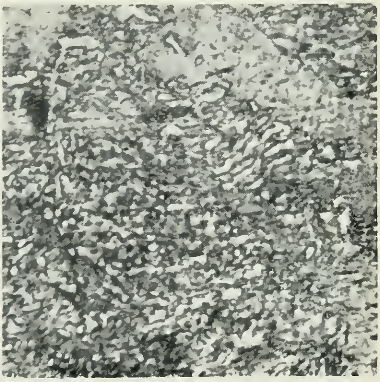


Fig. 33. × *140 diams.* Fig. 34. × *850 diams.*

Brymbo No. 12. 0 540 C.





Slowly Cooled Steels.

Fig. 35. *Brymbo No. 11.*
0·690 C. × 140 diams.

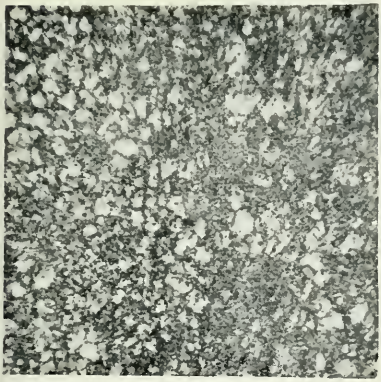


Fig. 36. *Cementation 1.D.*
0·552 C. × 850 diams.

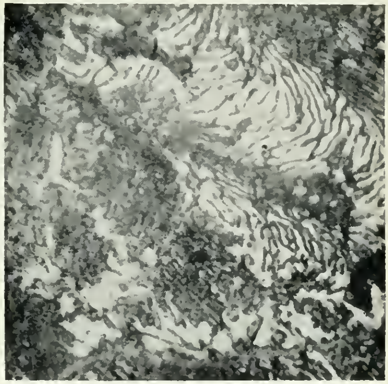


Fig. 37. *Brymbo No. 10.*
0 821 C. × 140 diams.

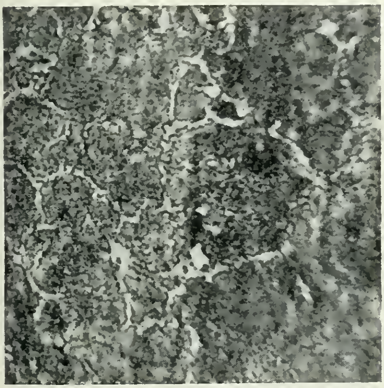


Fig. 38. *Die Steel.*
0·820 C. × 850 diams.

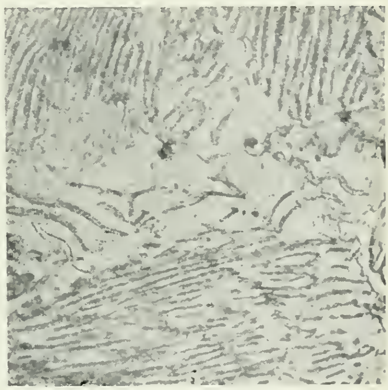
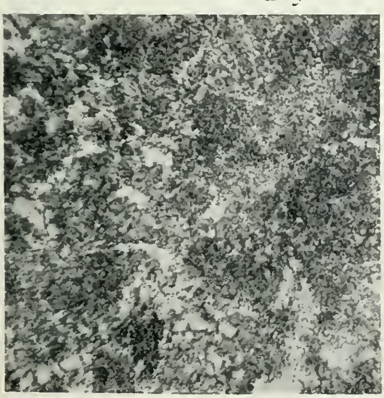
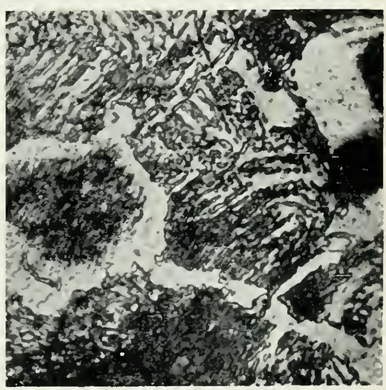


Fig. 39. *× 140 diams.*

Fig. 40. *× 850 diams.*

Brymbo No. 8. 0·927 C.

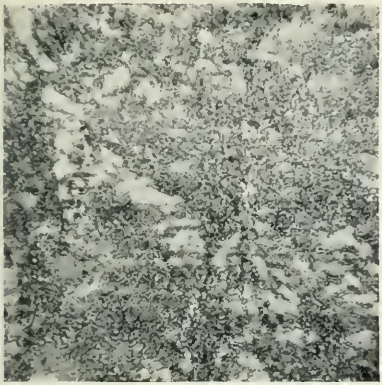




Slowly Cooled Steels.

Fig. 41. × *140 diams.* Fig. 42. × *850 diams.*

Brymbo No. 7. 1·161 C.



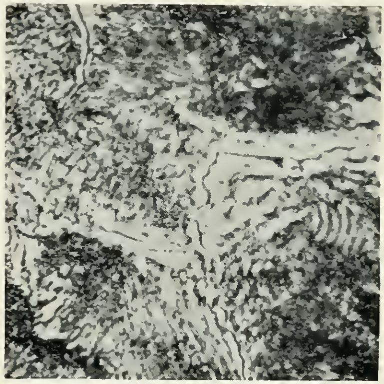
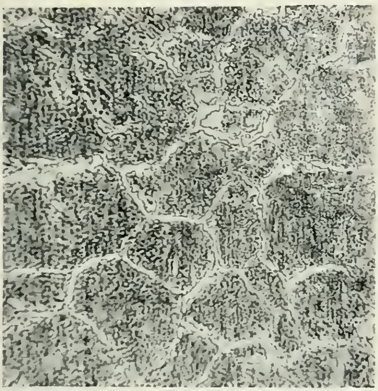


Fig. 43. × *140 diams.* Fig. 44. × *850 diams.*

Brymbo No. 5. 1·461 C.



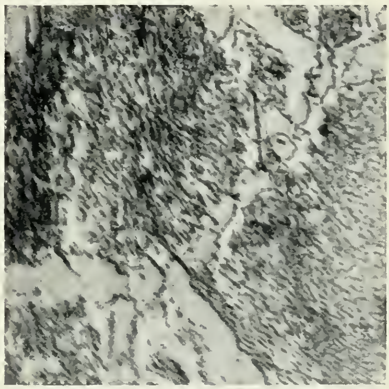
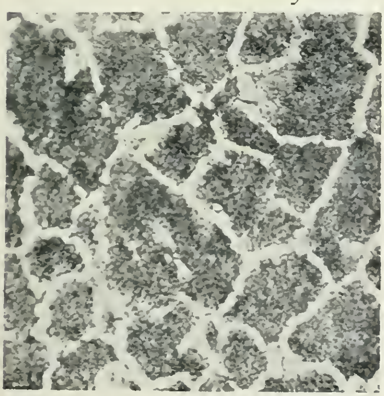
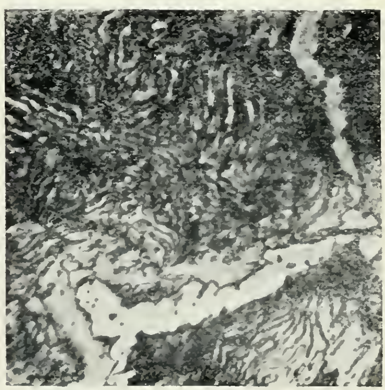


Fig. 45. × *140 diams.* Fig. 46. × *850 diams.*

Brymbo No. 1. 1·800 C.

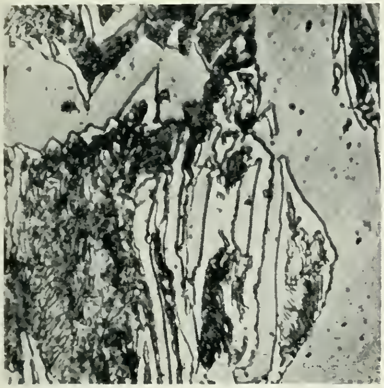




Cast-Iron Slowly Cooled. × *850 diams.*

Fig. 47. *White Iron.*
Combined C. = 2·573%.
Graphitic C. = 0·190%.

Fig. 48. *Grey Iron.*
Combined C. = 1·124%.
Graphitic C. = 2·640%.



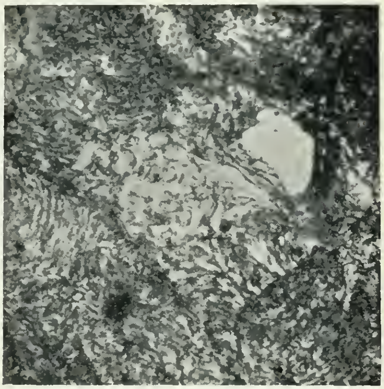
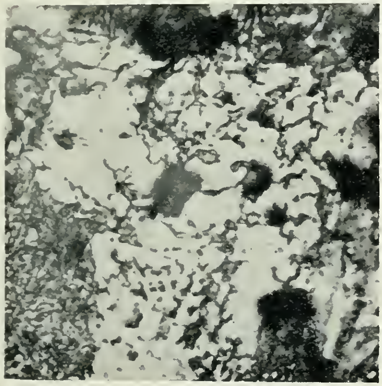


Fig. 49. *Total C. about 4·02%.* Fig. 50. *About 4·3% C.*

Grey Iron prepared in Electric Furnace.



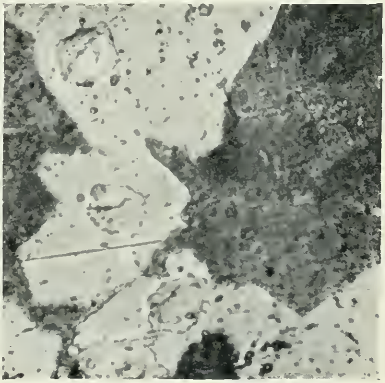
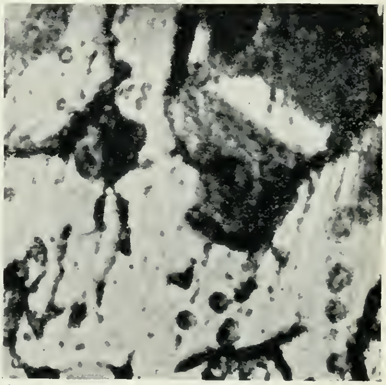


Fig. 51. *About 4·6% C.* Fig. 52. *About 5·2% C.*

Grey Iron prepared in Electric Furnace.



ALLOYS RESEARCH.

Rail Sections etched with warm dilute Sulphuric Acid.

Fig. 53. *Good Rail.*
0·54 C. 0·50 Mn. 0·16 P.

Rail 1.

Fig. 54. *Good Rail.*
0·40 C. 0·50 Mn. 0·07 P.

Rail 2.

Fig. 55. *Poor Rail.*
0·33 C. 0·70 Mn. 0·06 P.

Rail 3.

Fig. 56. *High Manganese Rail.*
0·41 C. 0·90 Mn. 0·07 P.

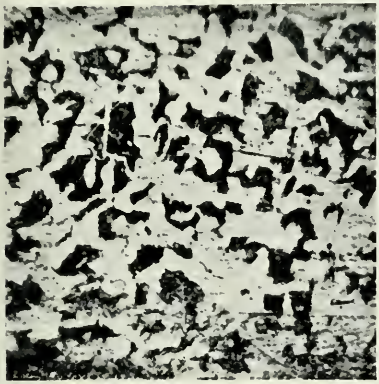
Rail 4.

Plate 13.

Rail Steel.

Rail 1, Plate 13. *Rail 2, Plate 13.*

Fig. 57. *Exterior of head* × *140 diams.* Fig. 58.



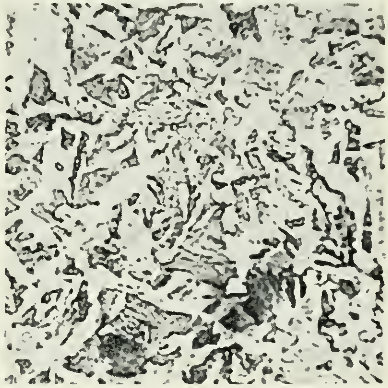


Fig. 59. *Interior of head* × *140 diams.* Fig. 60.

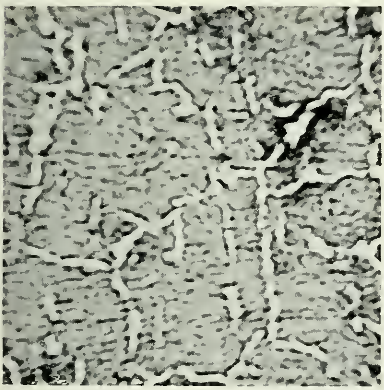
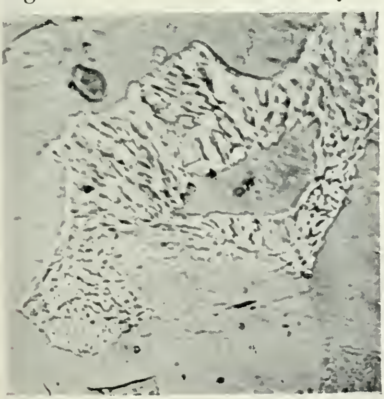
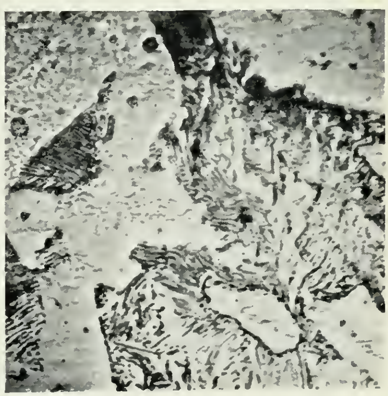


Fig. 61. *Pearlite of Rail* × *850 diams.* Fig. 62.

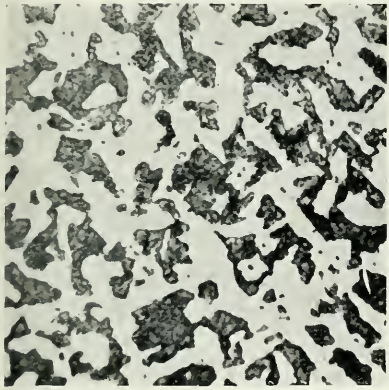




Rail Steel.

Rail 3, Plate 13. *Rail 4, Plate 13.*

Fig. 63. *Exterior of head × 140 diams.* Fig. 64.



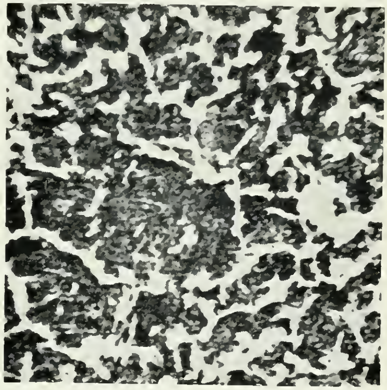
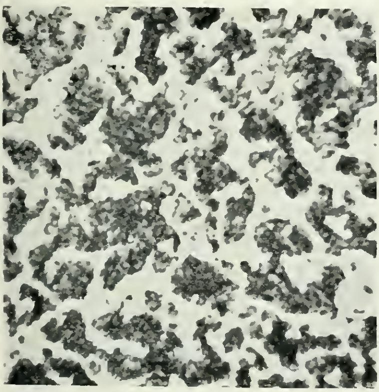


Fig. 65. *Interior of head × 140 diams.* Fig. 66.



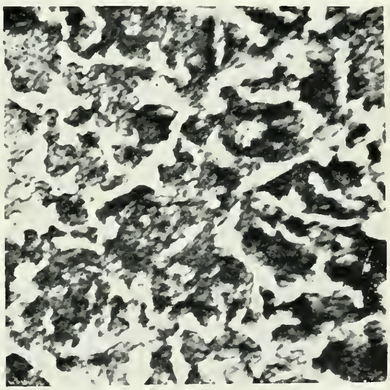
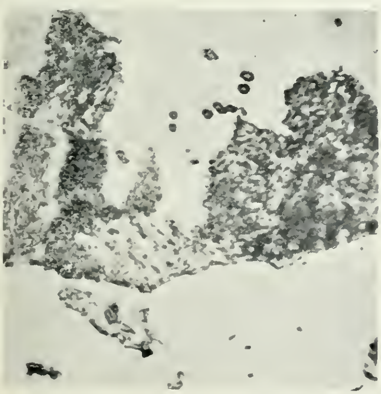


Fig. 67. *Pearlite of Rail × 850 diams.* Fig. 68.



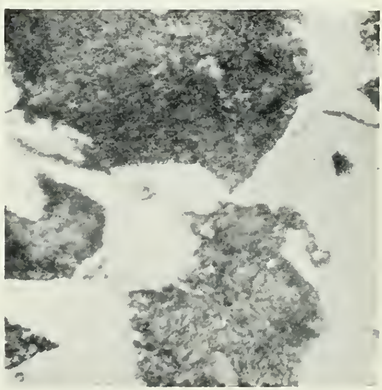


Photo-Micrographs of different parts in a transverse section of a good Steel Rail. × 1·10 diams.

Fig. 70.

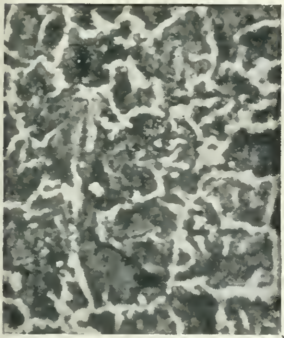


Fig. 71.

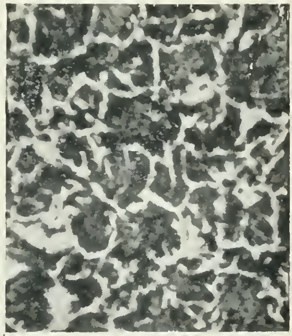


Fig. 69.

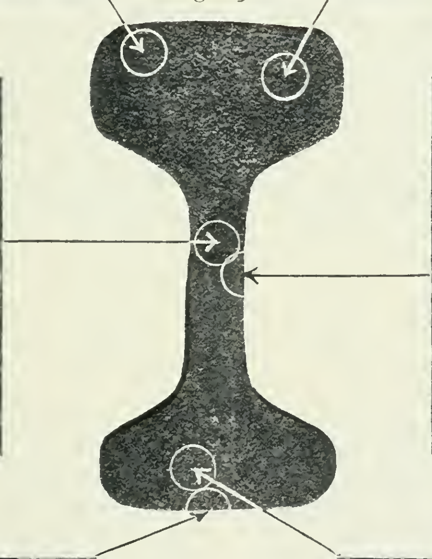


Fig. 72.

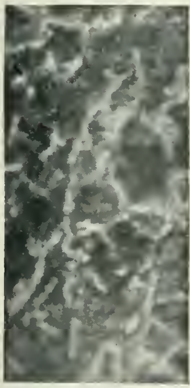


Fig. 73.

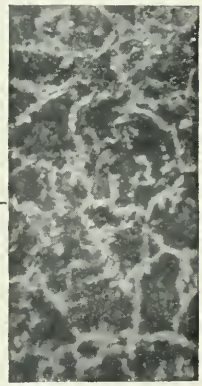


Fig. 74.

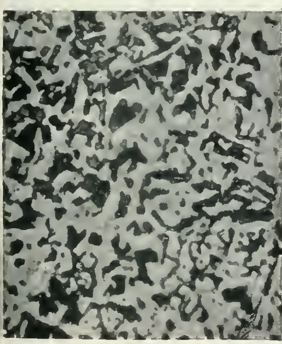


Fig. 75.

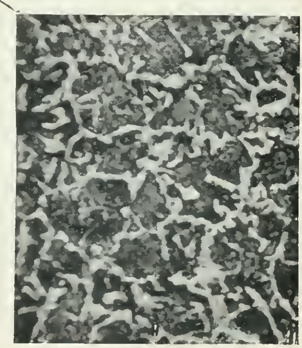


Photo-Micrographs showing that corresponding parts of transverse sections of a rail have the same structures, although they are ten feet apart in the length of the rail.

Fig. 76. *End of Rail.*
Interior of head.
× *140 diams.*

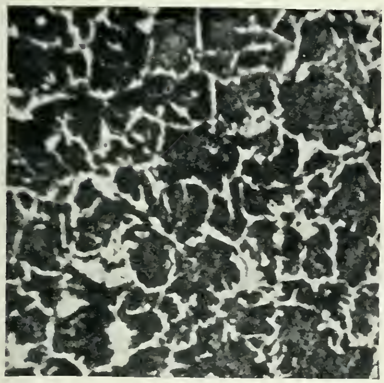


Fig. 77. *Middle of Rail.*
Interior of head.
× *140 diams.*

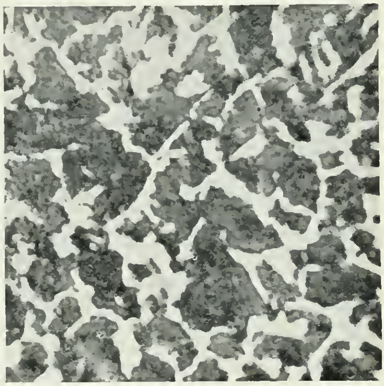


Fig. 78. *End of Rail.*
Interior of lower flange.
× *140 diams.*

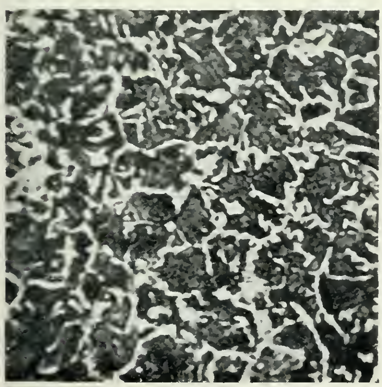
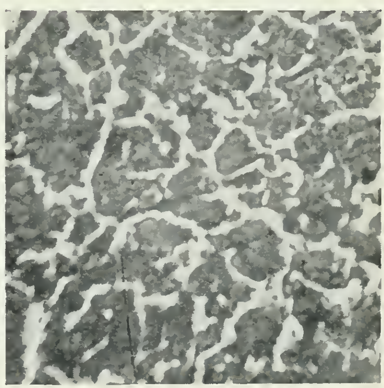


Fig. 79. *Middle of Rail.*
Interior of lower flange.
× *140 diams.*



Low-Carbon Rail.

Showing the effect of varying the Thermal treatment of the Steel.
× 850 diameters.

Fig. 80.
Rolled Rail.

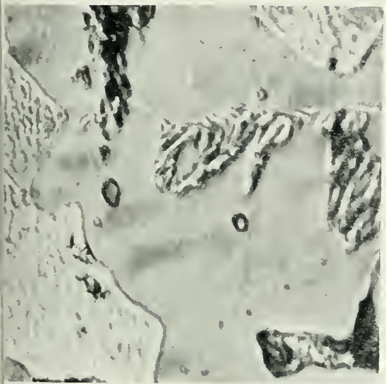


Fig. 81. *Annealed for 18 hours, at about 500° C. or 930° F.*

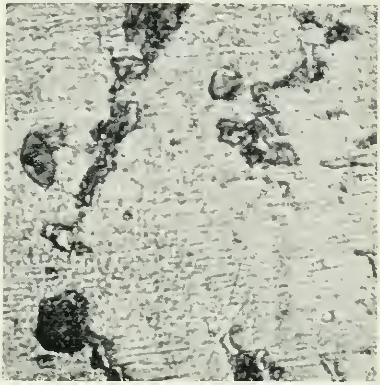


Fig. 82. *Troostite and Martensite. Quenched at 750° C. or 1,380° F.*

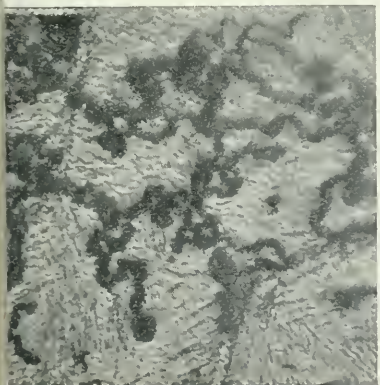
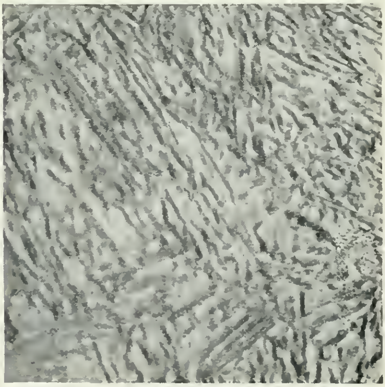


Fig. 83. *Martensite. Quenched above 1,000° C. or 1,830° F.*



Die Steel, containing 0·82% Carbon.
Showing the effect of varying the Thermal treatment of the Steel.
× 850 diameters.

Fig. 84. *Forged and Slowly Cooled.*

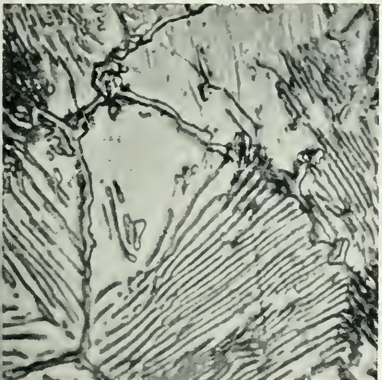


Fig. 85. *Annealed after Forging.*

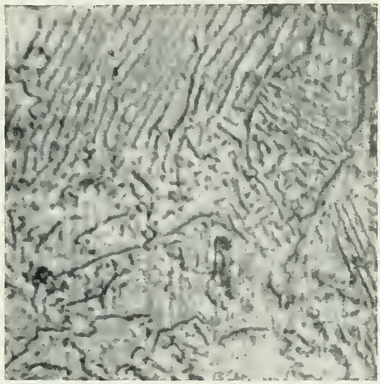


Fig. 86. *Quenched in Water at about 1,000° C. or 1,830° F.*

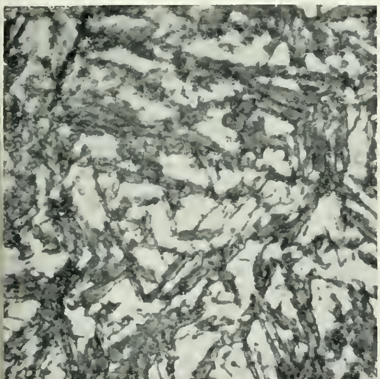
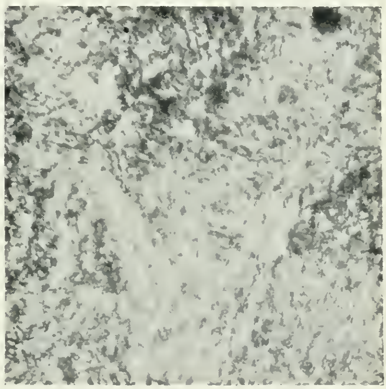


Fig. 87. *Tempered to Straw Color, about 243° C. or 470° F.*



g. 88. *Quenched at 750° C. or 1,380° F. Troostite, Martensite, and Ferrite.*

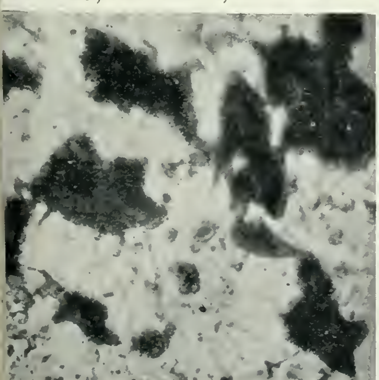
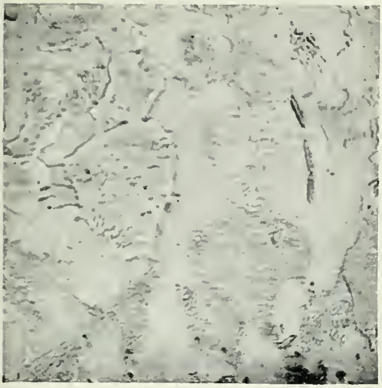


Fig. 89. *Burnt. Heated to over 1,100° C. or 2,000° F. Graphite visible.*

Chrome Steel, magnified 850 diameters.

Fig. 90. *Soft.* *Tire and Axle Steel. 0·32 Cr. 0·44 C.* Fig. 91. *Hard.*



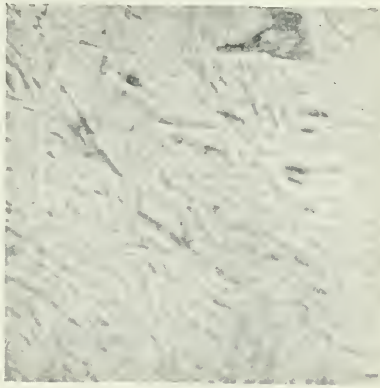
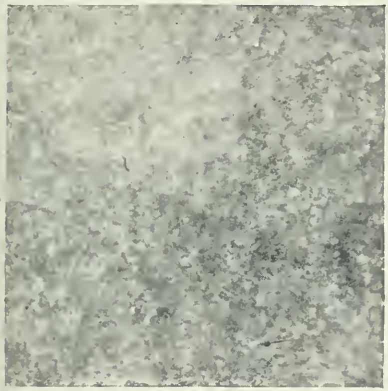


Fig. 92. *Soft.* *Tool Steel 0·46 Cr. 0·85 C.* Fig. 93. *Hard.*



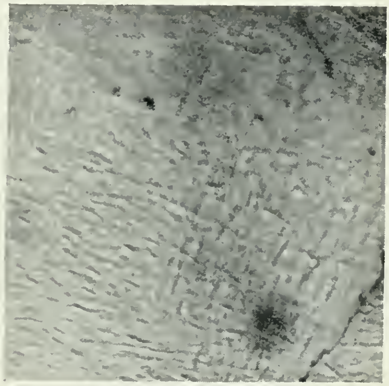


Fig. 94. *Soft.* *Spring Steel. 0·17 Cr. 0·78 C.* Fig. 95. *Hard.*

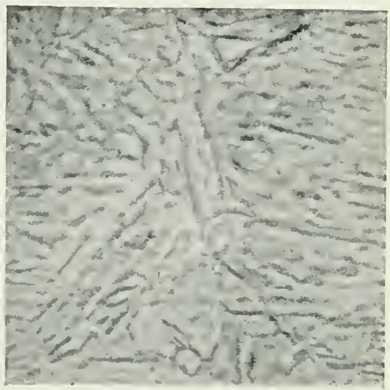


Photo-Micrographs of Steel and Iron.

Fig. 96. *Soft Swedish Steel.*
0·01% Carbon × 50 diams.

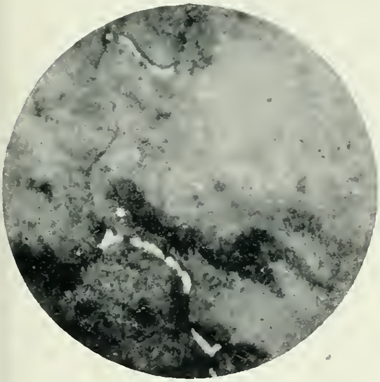


Fig. 97. *Martensite structure in soft steel.*
0·15% Carbon × 50 diams.

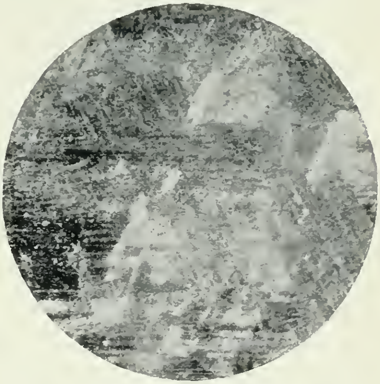


Fig. 98. *Steel cooled in slag.*
0·27% Carbon × 200 diams.

Fig. 99. *Tool Steel cooled in slag.*
1·38% Carbon × 30 diams.

Fig. 100. *Brittle Casting*
[m]eshed with Sulphide of Manganese.

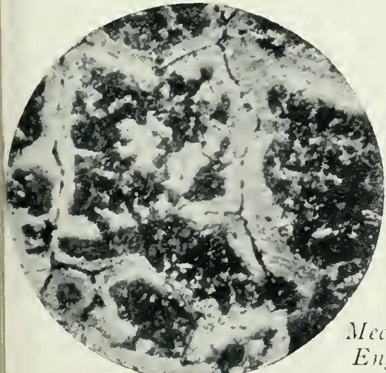
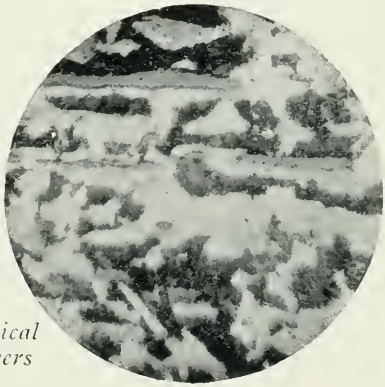


Fig. 101. *Steel Rail Head,*
longitudinal section × 130 diams.



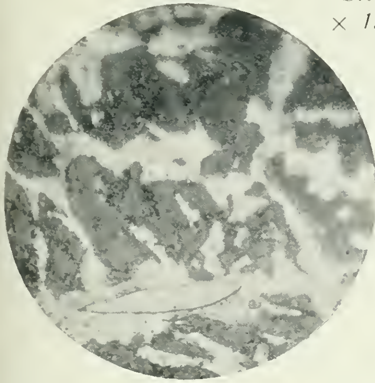
Mechanical Engineers 1899.

Photo-Micrographs of Steel and Iron.

Fig. 102. *Before crushing.*

Steel Shaft,
× 130 diams.

Fig. 103. *After crushing.*



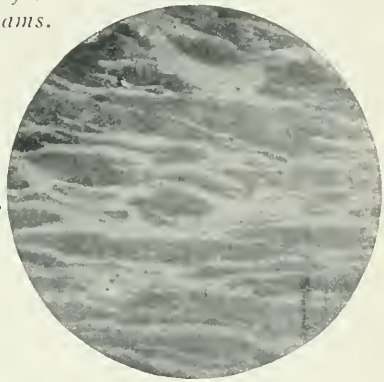


Fig. 104. *Wrought-Iron Shaft, longitudinal section × 50 diams.*

Fig. 107. *Surface of worn Locomotive Tire × 50 diams.*

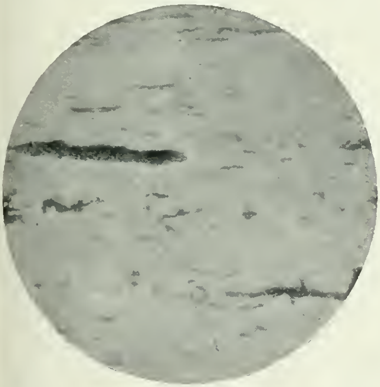
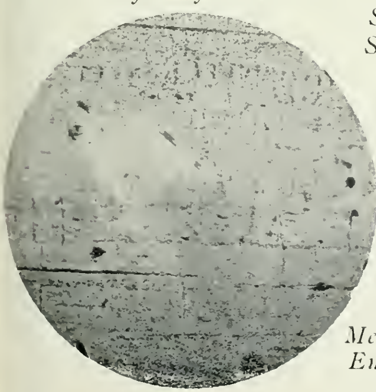
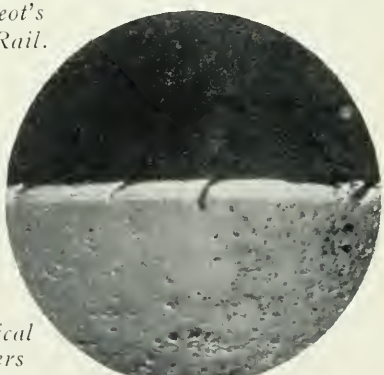


Fig. 105. *Natural size. Surface of Head.*

Fig. 106. *× 10 diams. Longitudinal vertical section.*

St. Neot's
Steel Rail.





Mechanical
Engineers
1899.

Fig. 108. *Coarsely Granular Annealed Soft Steel, containing 0·12% Carbon.*

Before heating to just above Ar3. *After heating to just above Ar3.*

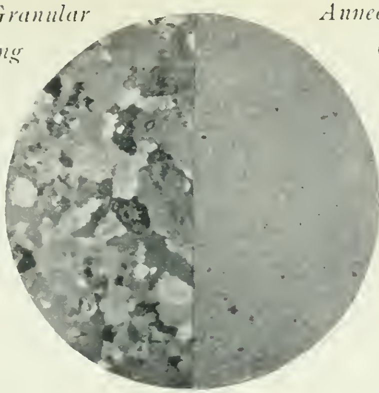


Fig. 109. *Iron and Carbon, cooled rapidly.*

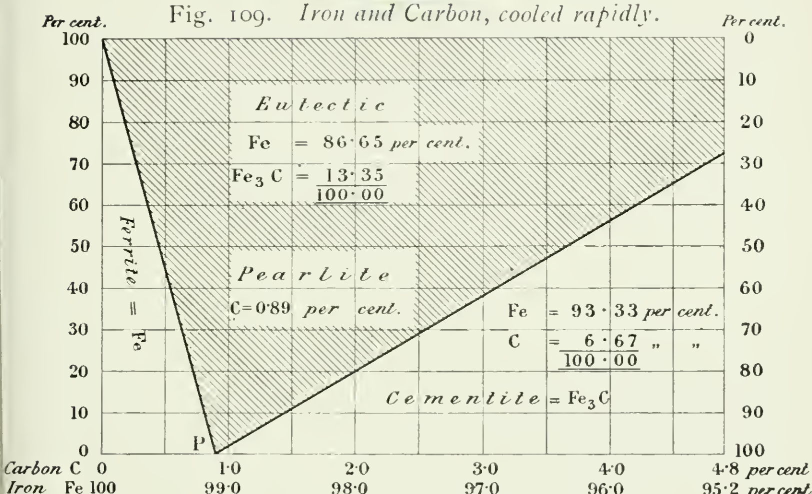
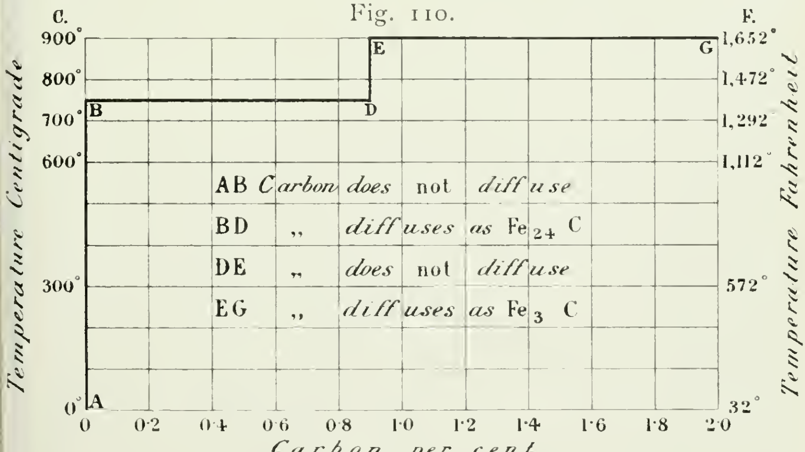


Fig. 110.



Mechanical Engineers 1899.

TYPOGRAPHIC PRINTING MACHINERY.

Plate 24.

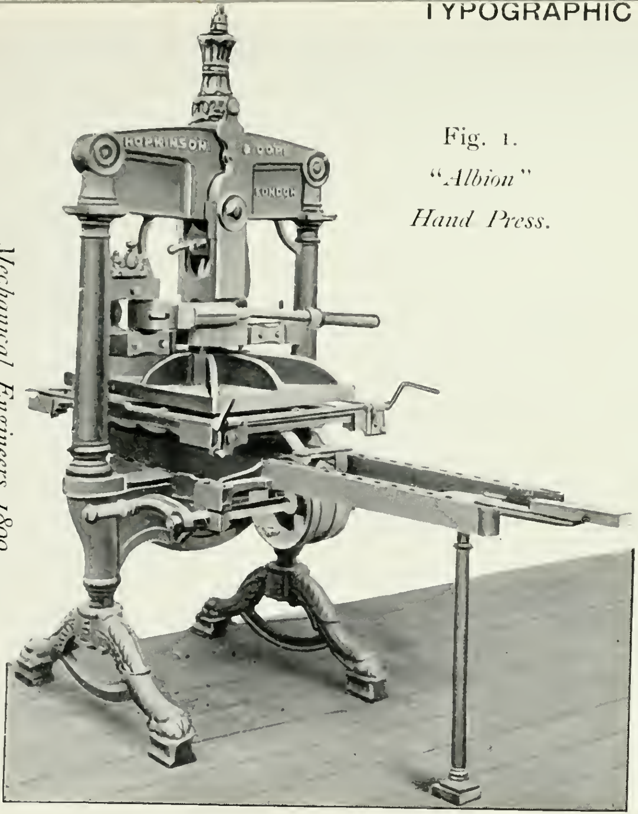


Fig. 1.
"Albion"
Hand Press.

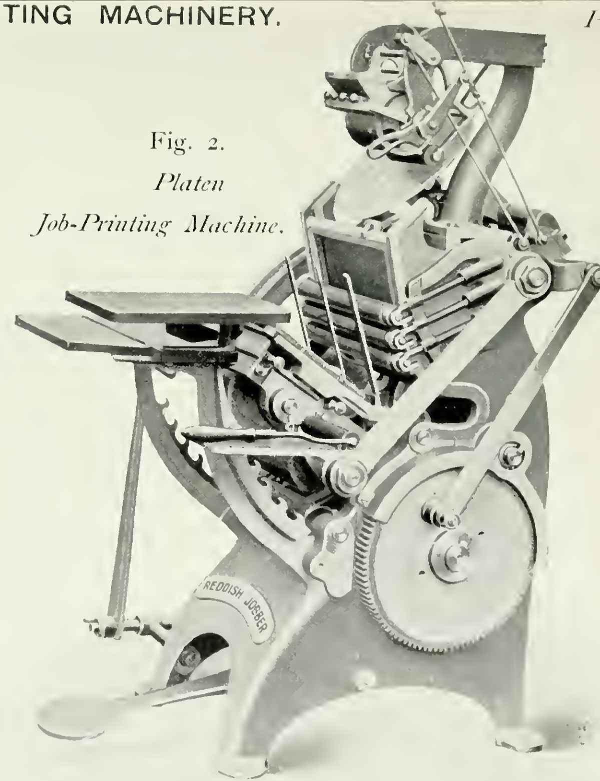


Fig. 2.
Platen
Job-Printing Machine.

TYPOGRAPHIC PRINTING MACHINERY.

"Albion" Hand Press.

Fig: 3.

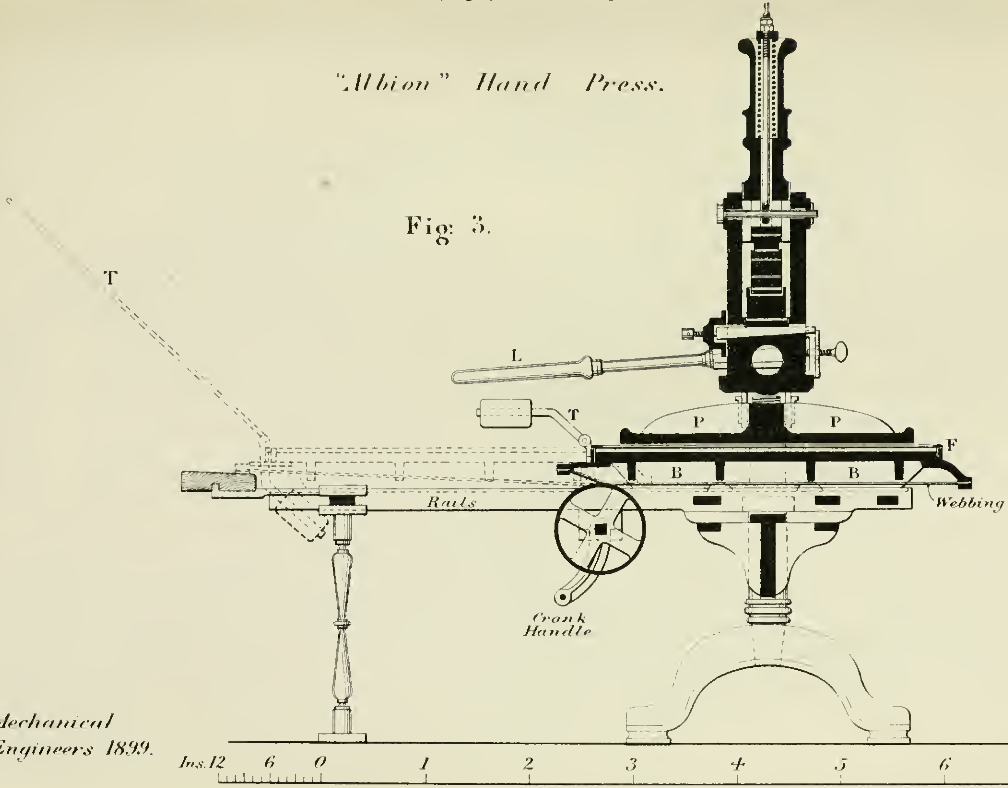
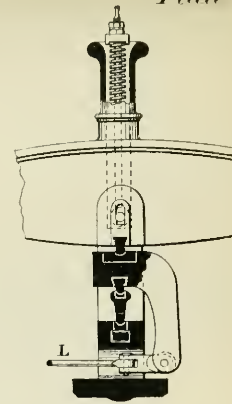


Fig: 4.



Mechanical
Engineers 1899.

Plate 25.

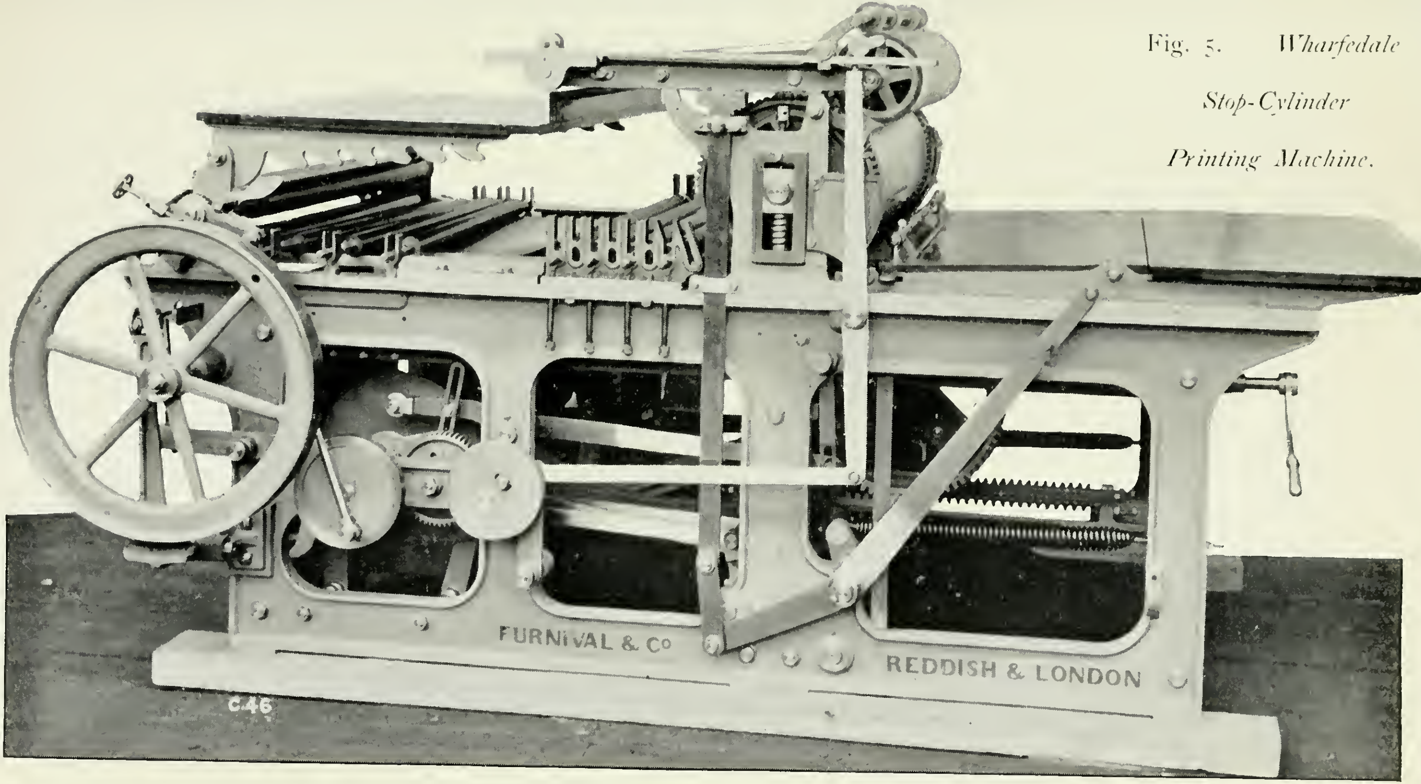
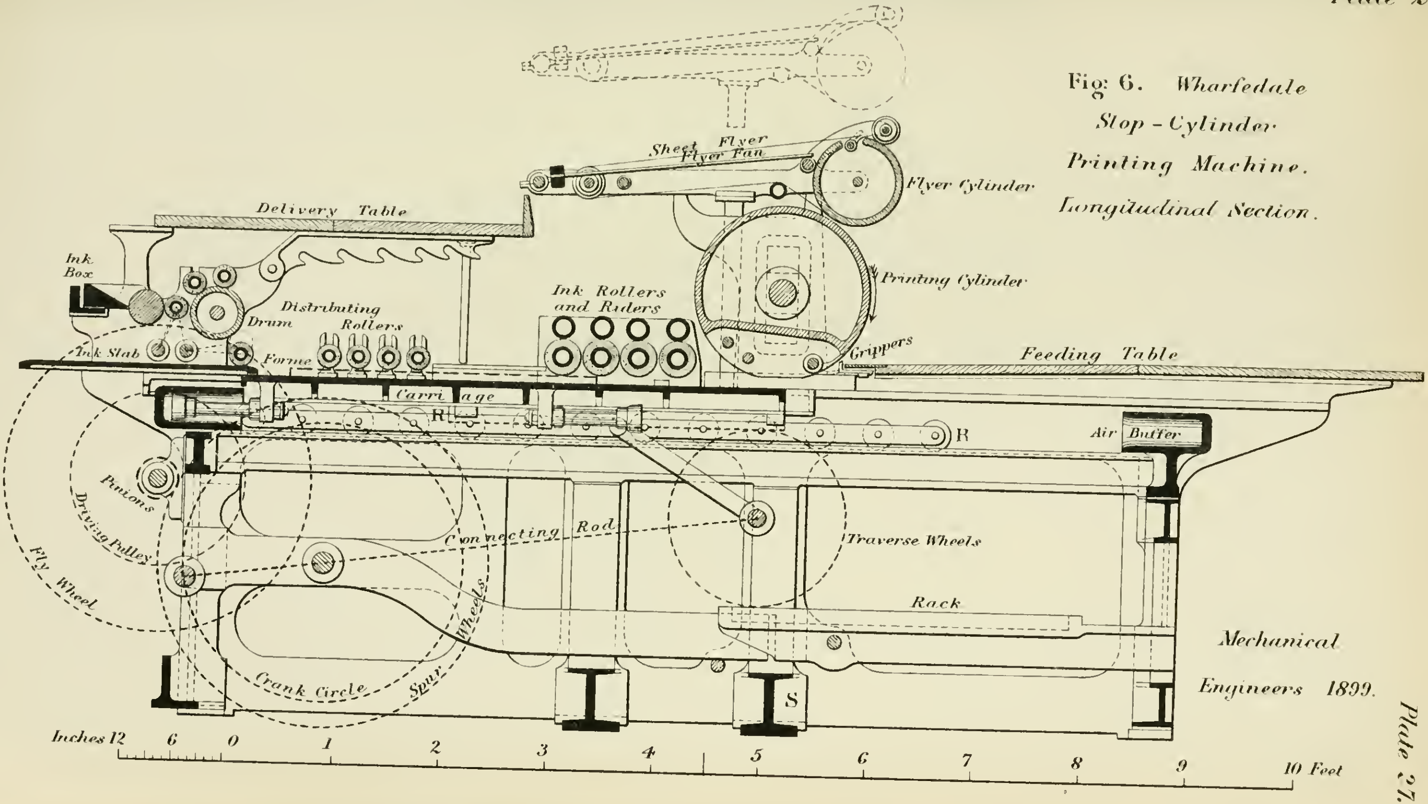


Fig. 5. *Wharfedale Stop-Cylinder Printing Machine.*

TYPOGRAPHIC PRINTING MACHINERY.

Plate 27.

Fig: 6. Wharfedale Stop-Cylinder Printing Machine. Longitudinal Section.



Mechanical Engineers 1899.

TYPOGRAPHIC PRINTING MACHINERY.

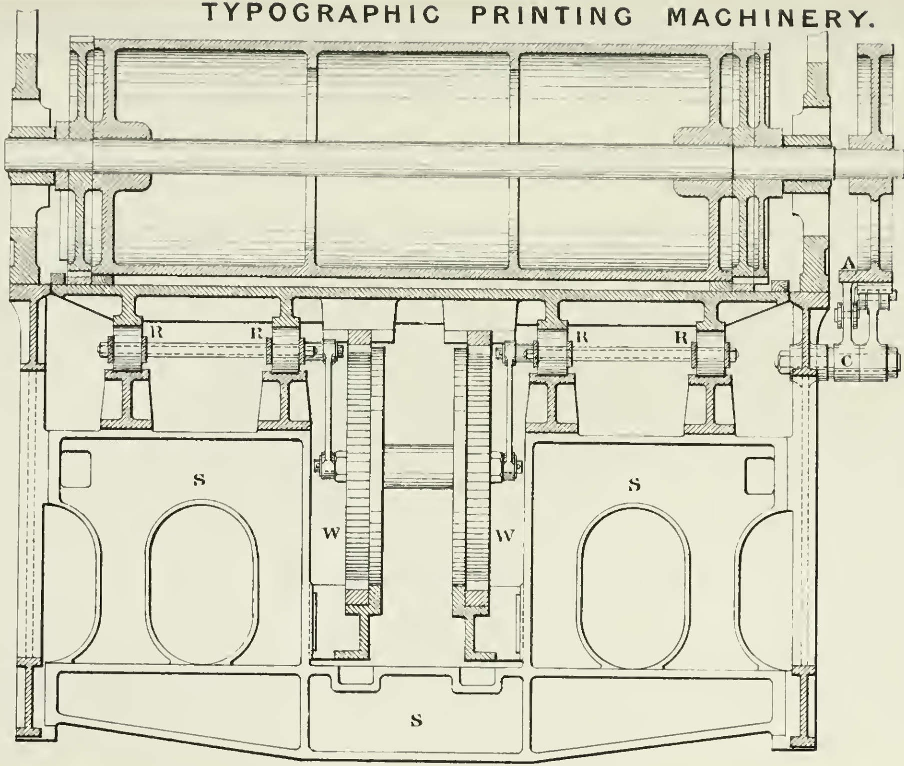


Fig. 7.
Wharfedale
Stop-Cylinder
Printing Machine.
Cross Section.

Scale 1/16th.

Plate 28.

Wharfedale Stop-Cylinder Printing Machine.

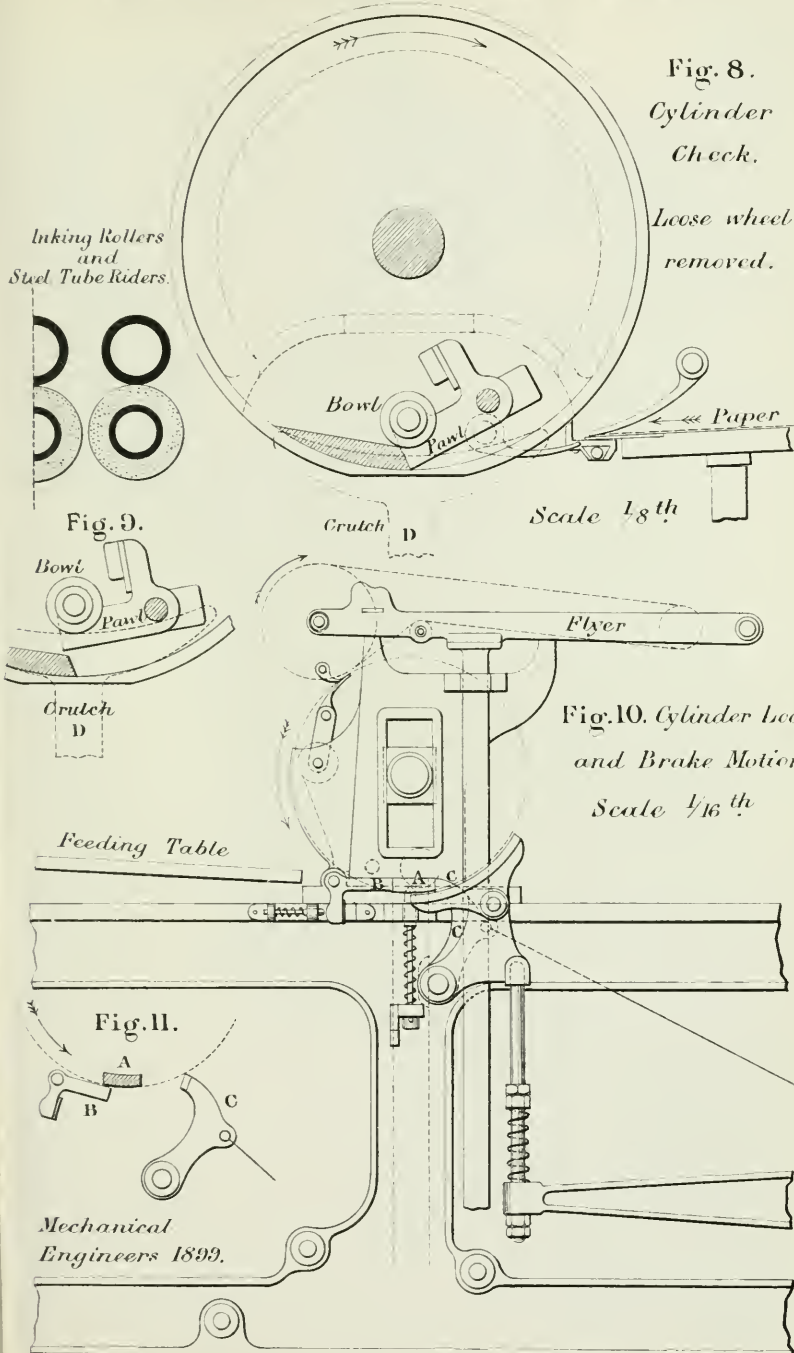


Fig. 12. *Fine-Art Stop-Cylinder Printing Machine.*

In working position.

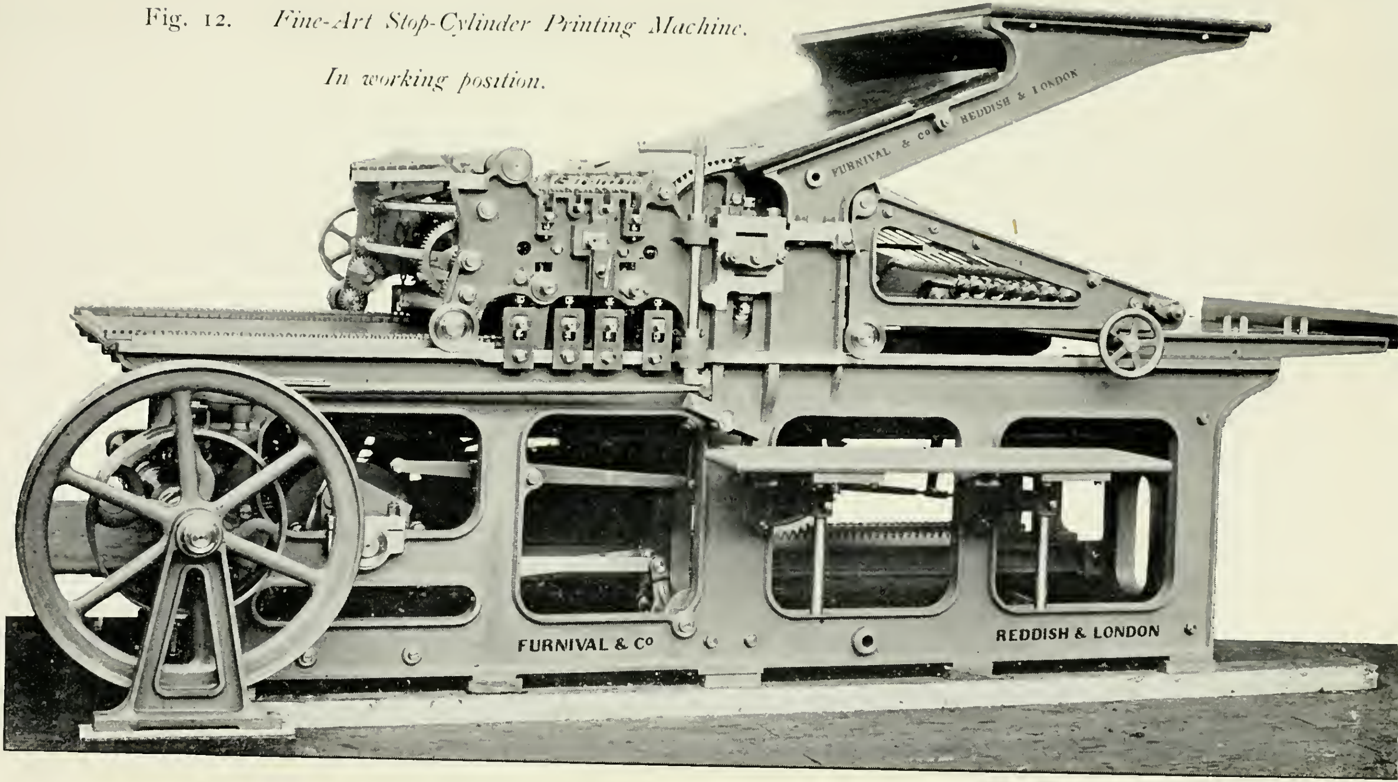


Fig. 13. *Fine-Art Stop-Cylinder Printing Machine.*

In cleaning position.

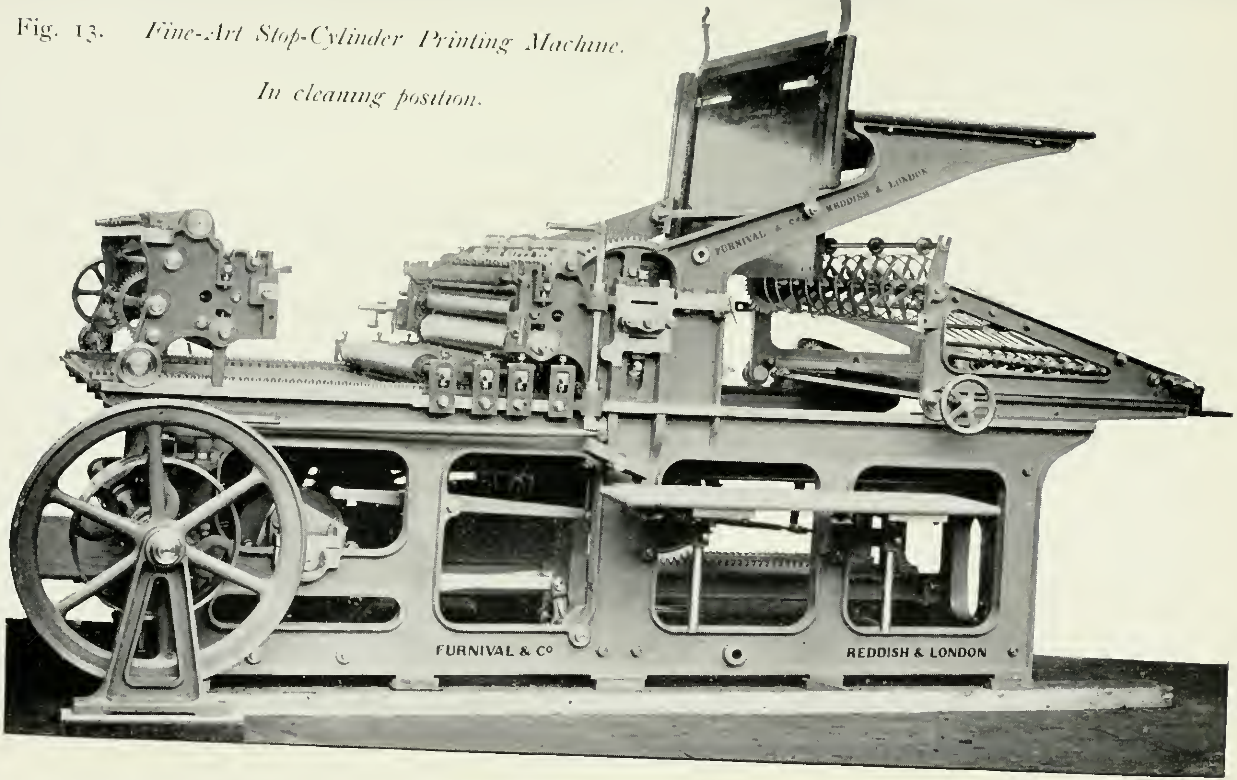
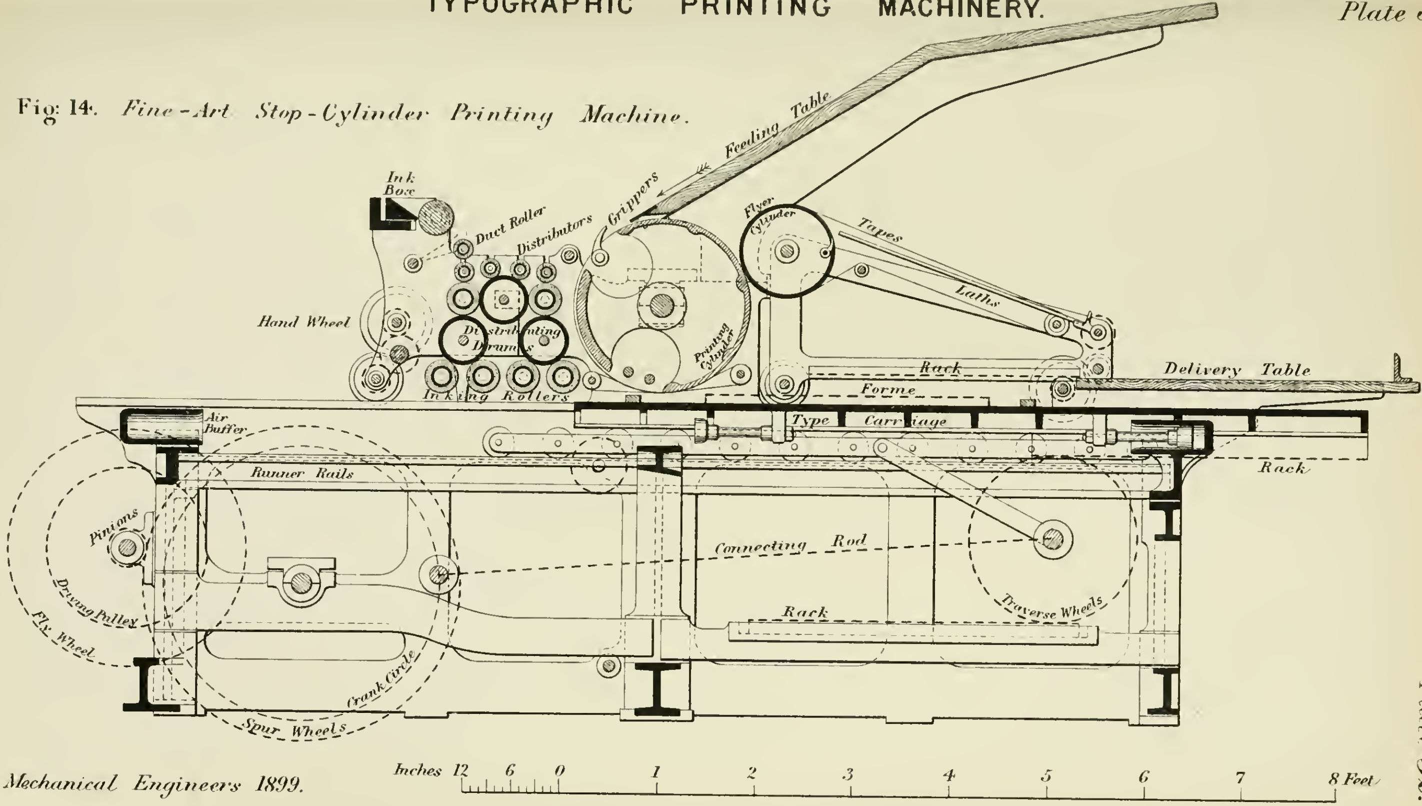


Fig: 14. *Fine-Art Stop-Cylinder Printing Machine.*



Mechanical Engineers 1899.

Fig. 15. *Fine-Art Stop-Cylinder Printing Machine*

Lay Attachment.

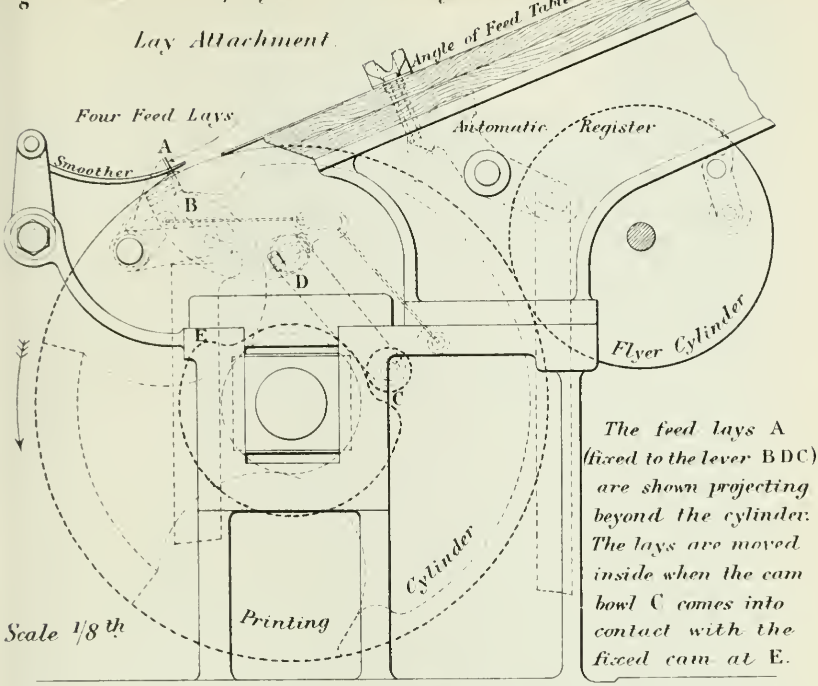


Fig. 16. *Two-Revolution Single-Cylinder Printing Machine.*

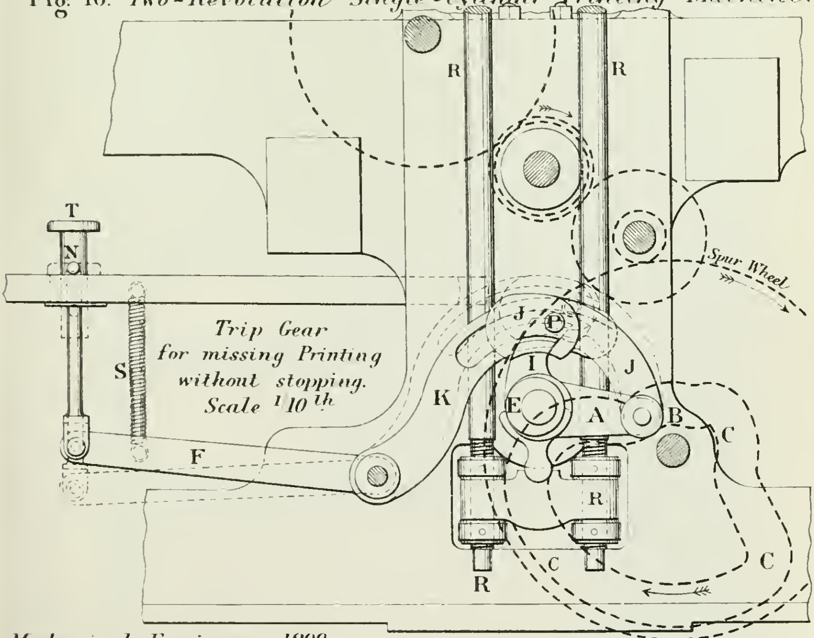


Fig. 17. *Two-Revolution Single-Cylinder Printing Machine.*

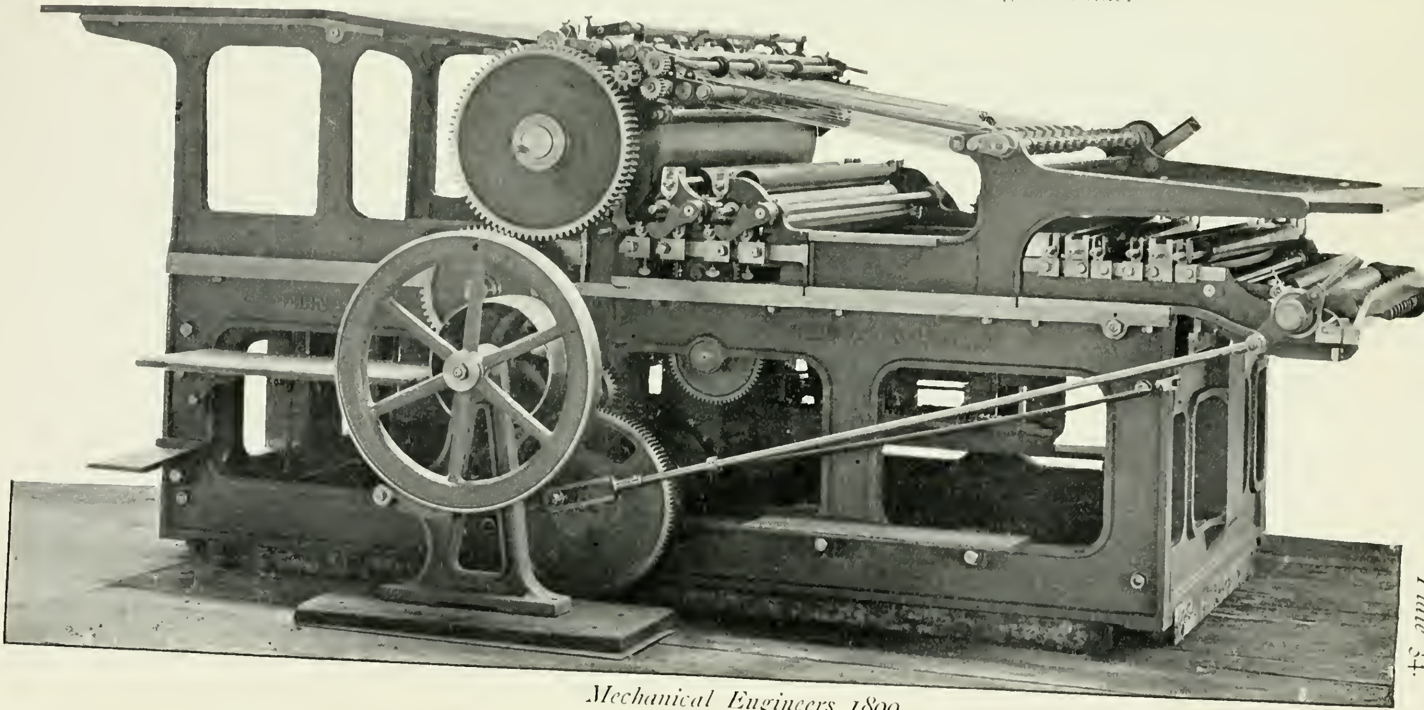
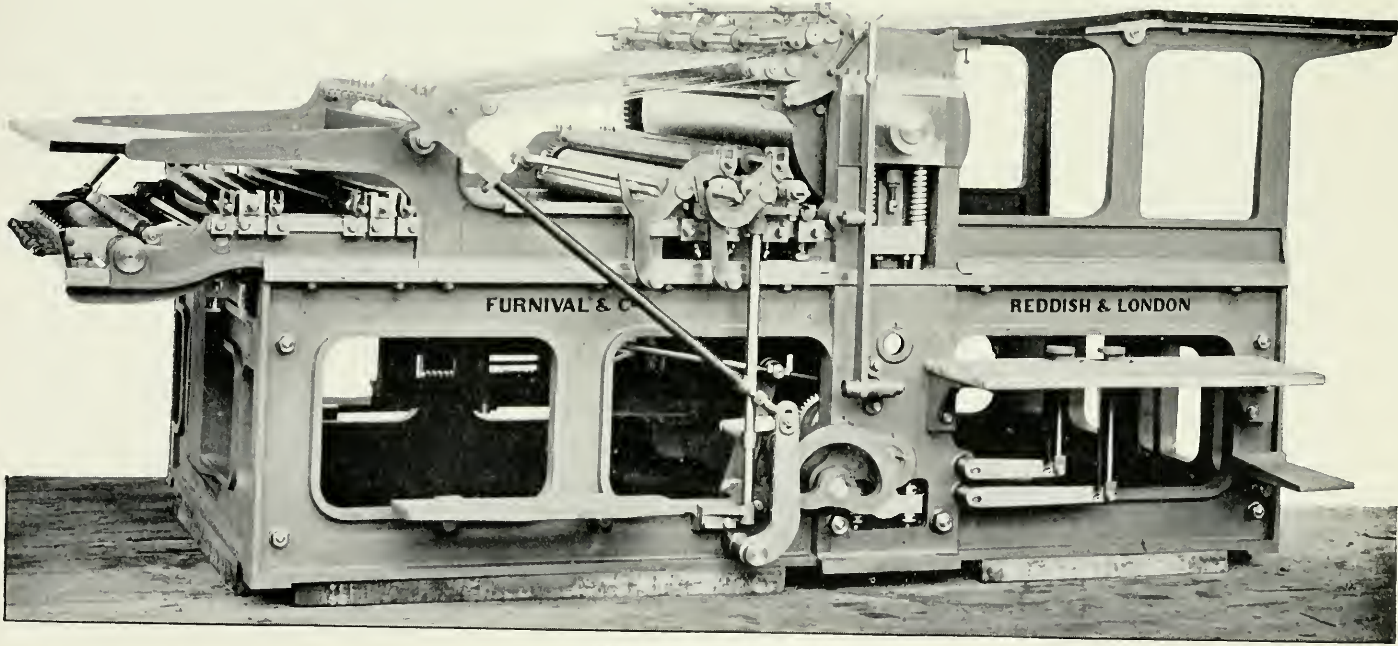
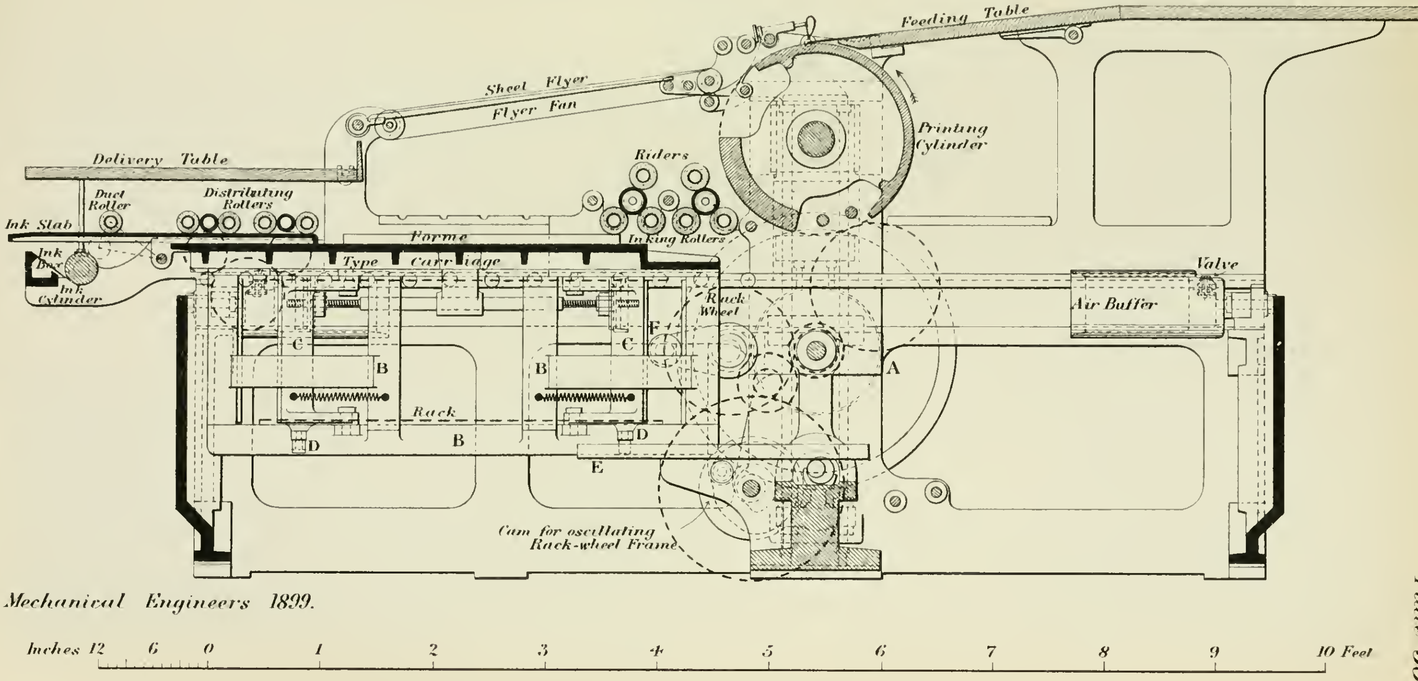


Fig. 18. *Two-Revolution Single-Cylinder Printing Machine.*



Mechanical Engineers 1899.

Fig: 19. *Two-Revolution Single-Cylinder Printing Machine.*



Mechanical Engineers 1899.

Fig. 20. *Wharfedale Two-Colour Printing Machine.*

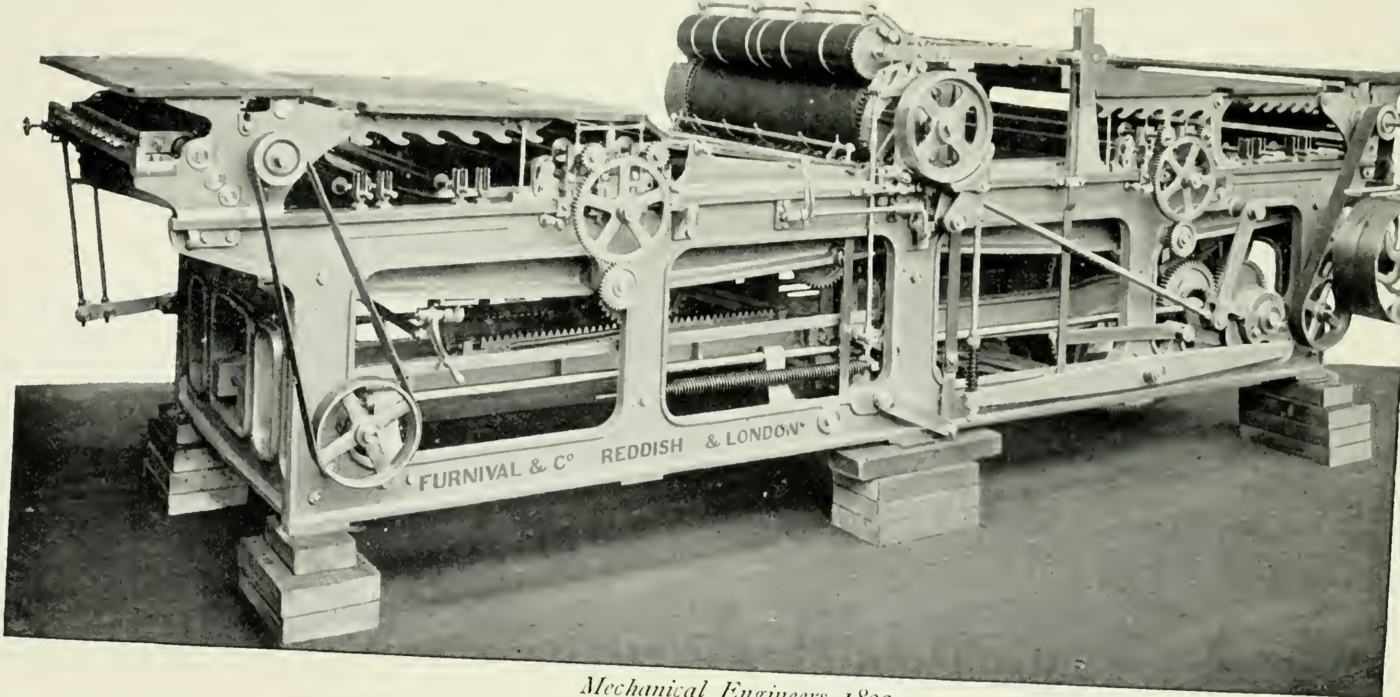
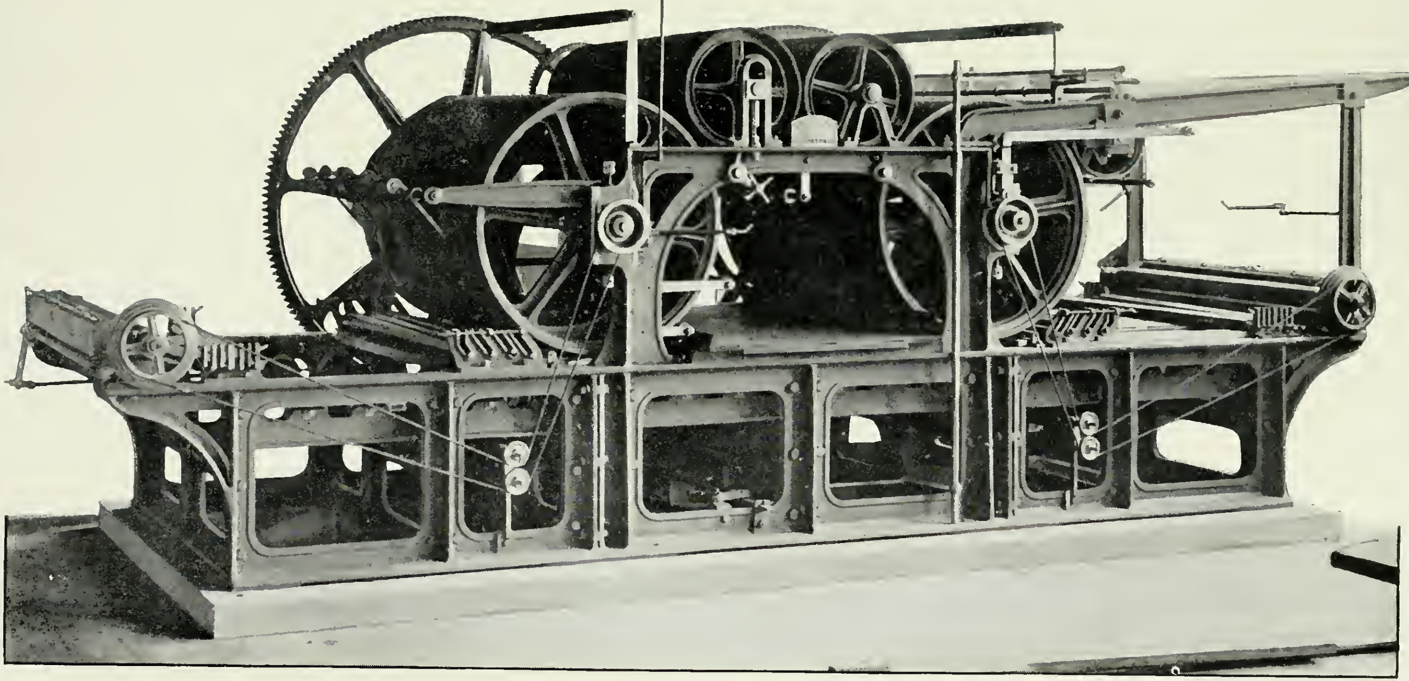


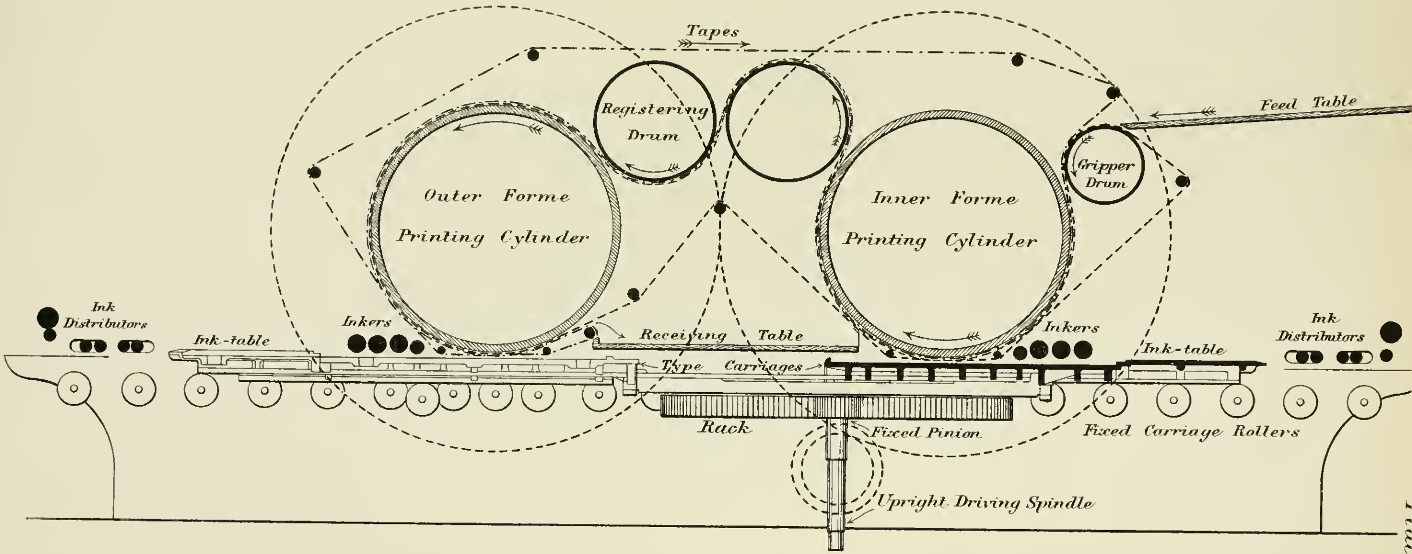
Fig. 21. *Single-Revolution "Perfector" Printing Machine.*



TYPOGRAPHIC PRINTING MACHINERY.

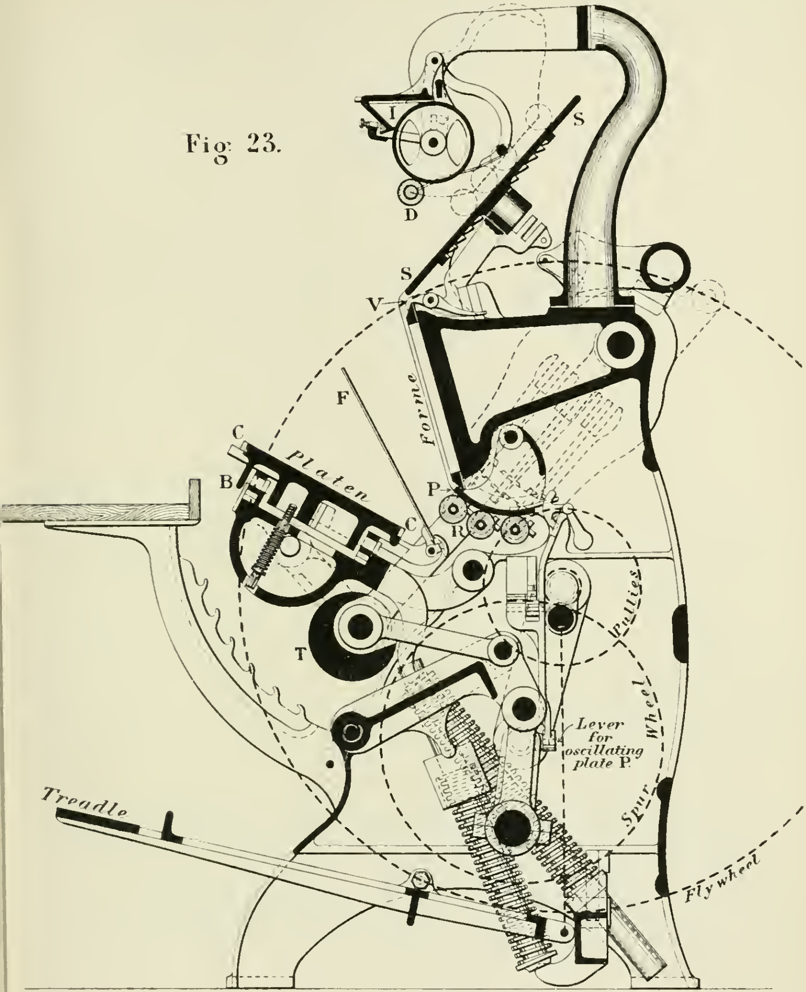
Fig. 22. *Single-Revolution "Perfector" Printing Machine.*

Printing both sides.



Platen Job-Printing Machine.

Fig. 23.



Front view of Platen showing arrangement of "Throw-off" and Impression Adjustment.

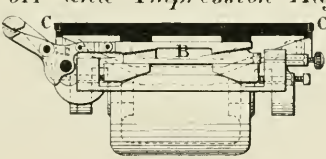


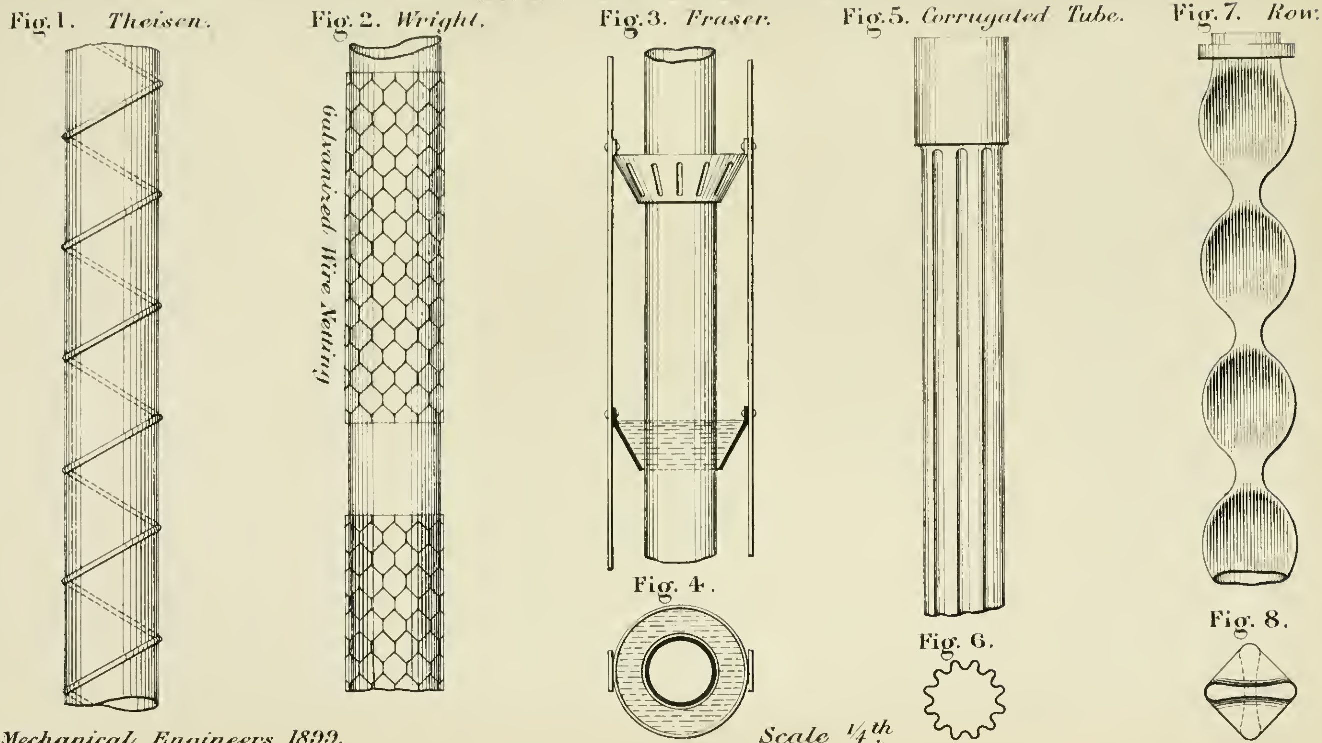
Fig. 24.

Mechanical Engineers 1899.

Inches 12 6 0 1 2 Feet

EVAPORATIVE CONDENSERS.

Details of Vertical Tubes.



Scale ¼th.

Distribution of Water over Tubes.

Fraser Horizontal. Tank with Perforated Pipe.

Fig. 9.

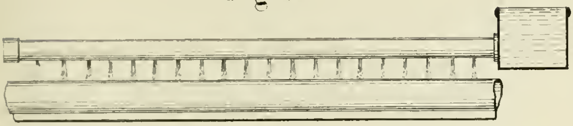
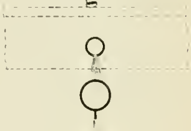


Fig. 10.



Horizontal. Tank with Slotted Pipe.

Fig. 11.

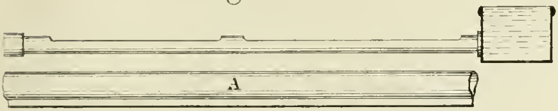
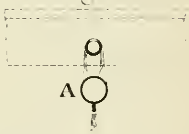


Fig. 12.



Enlarged views of wrought-iron Tube A.

Fig. 13.

Fig. 14.

Fig. 15.

Spiral Distributor

Ledward Perforated Pipe with Corrugated c.i. Tube.

Fig. 16.

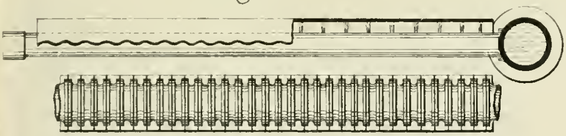


Fig. 17.

Fig. 18.

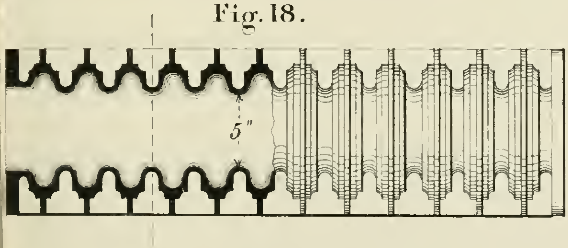
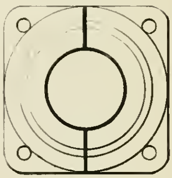


Fig. 19.



Distribution of Water over Tubes.

Wooden – Trough Distributor.

Fig. 20.

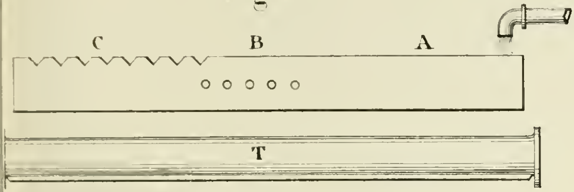
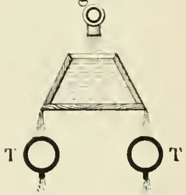


Fig. 21.



Enlarged views of cast-iron Tube T

Fig. 22.

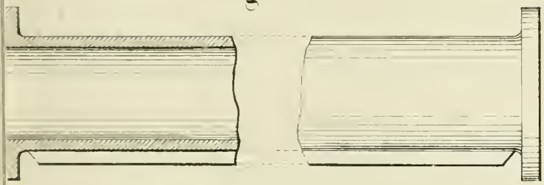
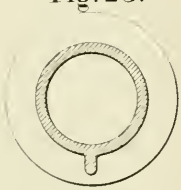


Fig. 23.



V *Notch Trough.*

Fig. 24.

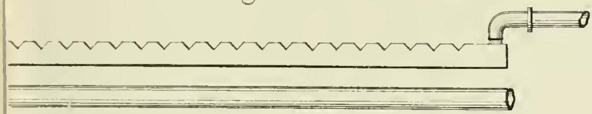
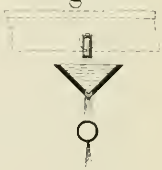


Fig. 25.

V *Perforated Trough.*

Fig. 26.

Fig. 27.



EVAPORATIVE CONDENSERS.

Jointing Tubes, and Water-Seal.

Fig: 28. *Fraser* *Vertical Brass Tubes.*

Horizontal Tubes.

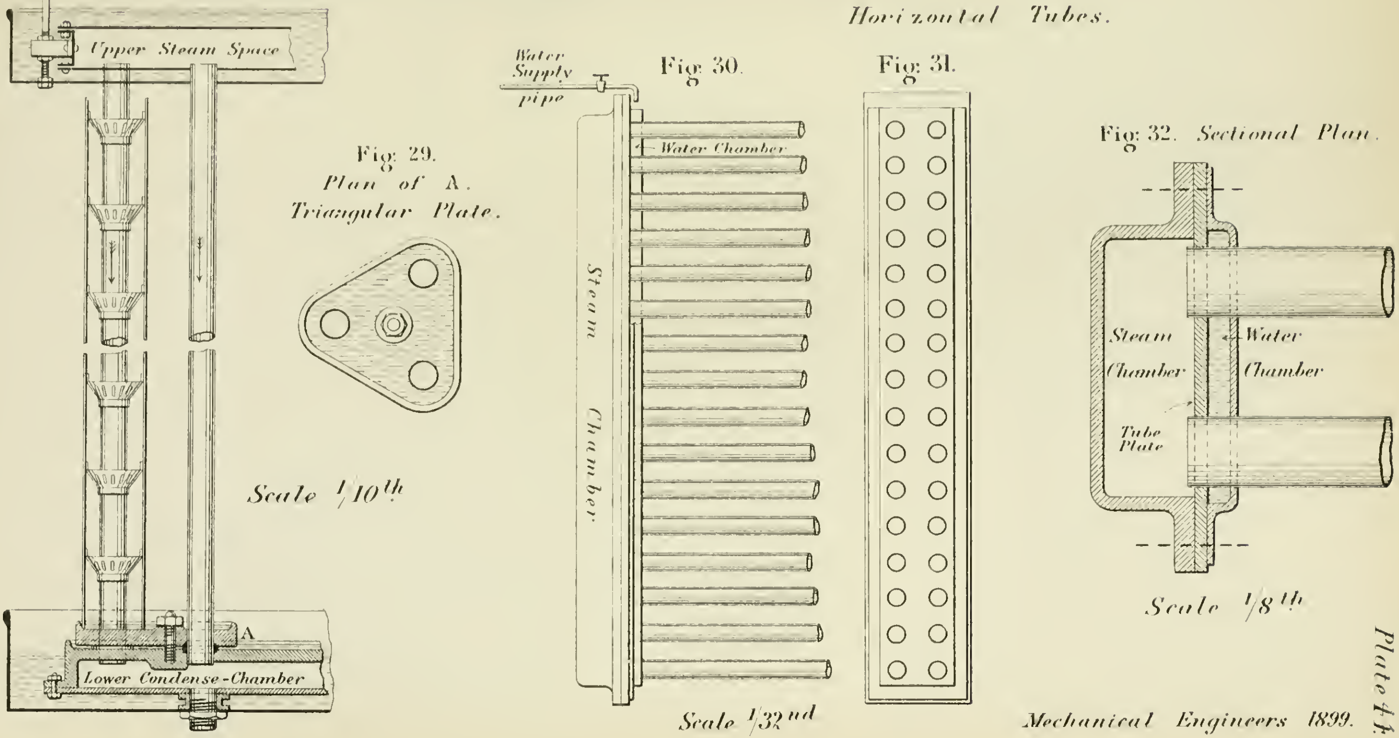


Fig: 29. *Plan of A. Triangular Plate.*

Scale 1/10th.

Fig: 30.

Fig: 31.

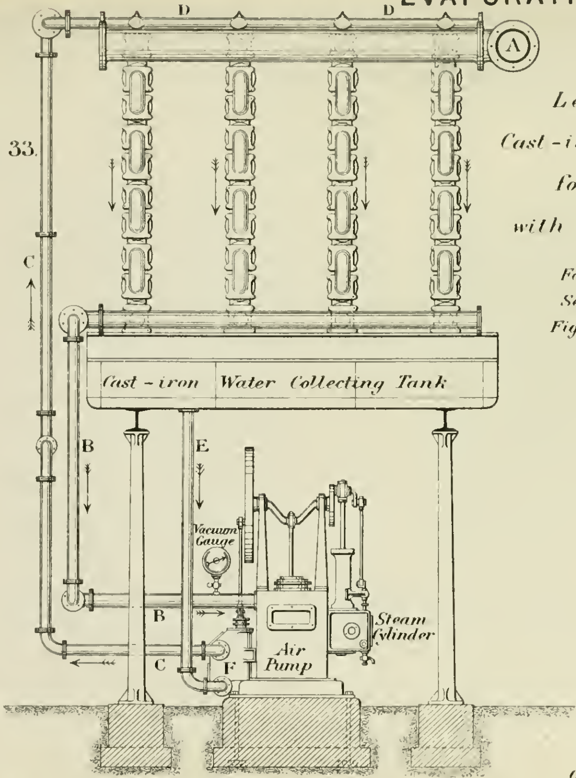
Scale 1/32nd

Fig: 32. *Sectional Plan.*

Scale 1/8th.

EVAPORATIVE CONDENSERS.

Fig. 33.



Ledward Cast-iron Condenser for 150 H.P. with Air Pump.

For Detail See Plate 42. Figs. 18 and 19.

Fig. 34.

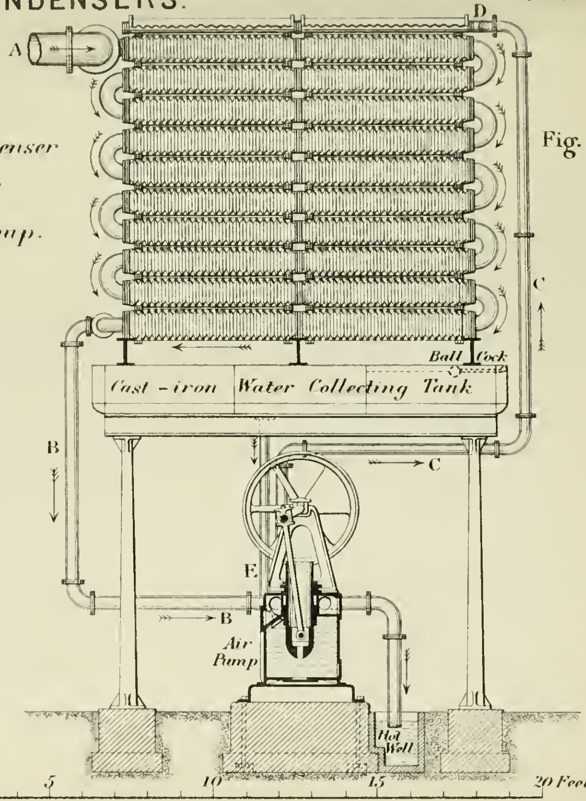


Plate 45.

EVAPORATIVE CONDENSERS.

Ledward Evaporative Condenser.

Chapel Street, Knightsbridge.

Fig: 35.

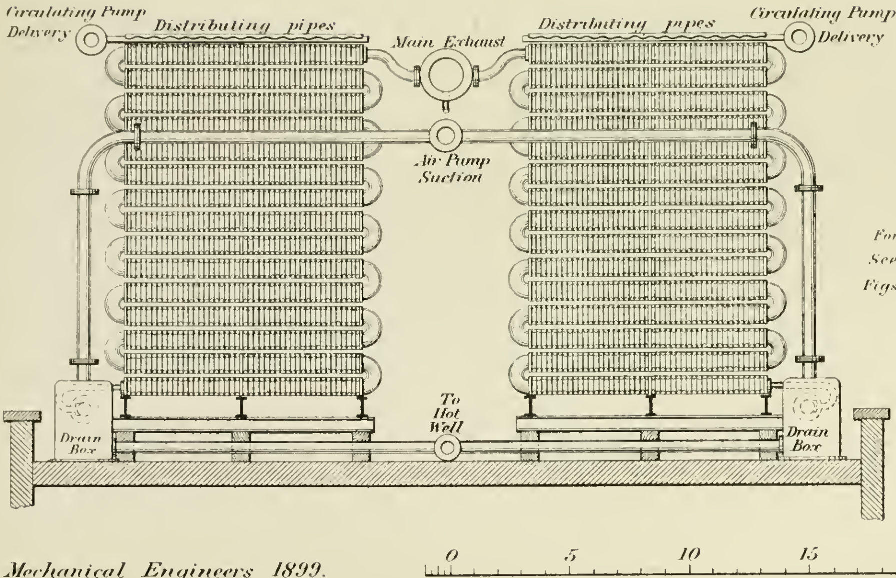
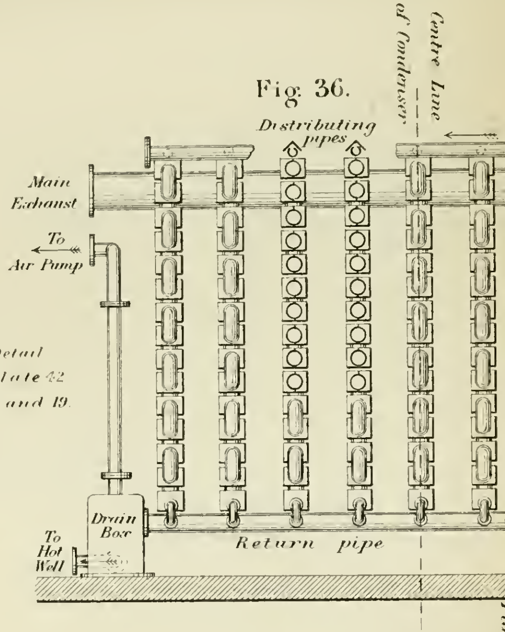


Fig: 36.



For Detail
See Plate 42
Figs. 18 and 19.

EVAPORATIVE CONDENSERS.

Horizontal Cast-iron-tube Type.

Fig: 37.

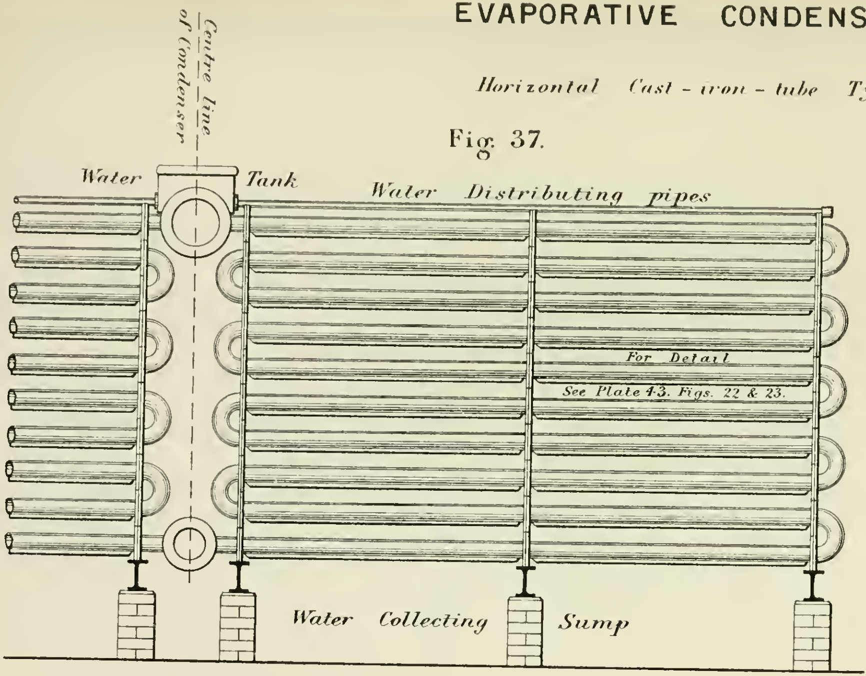
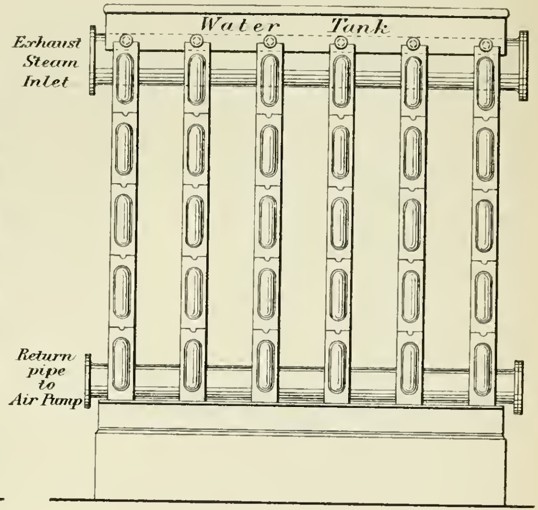


Fig: 38.



Inches 12 6 0 5 10 Feet 15

EVAPORATIVE CONDENSERS.

Fraser Horizontal Wrought-iron-tube Type at Waterloo.

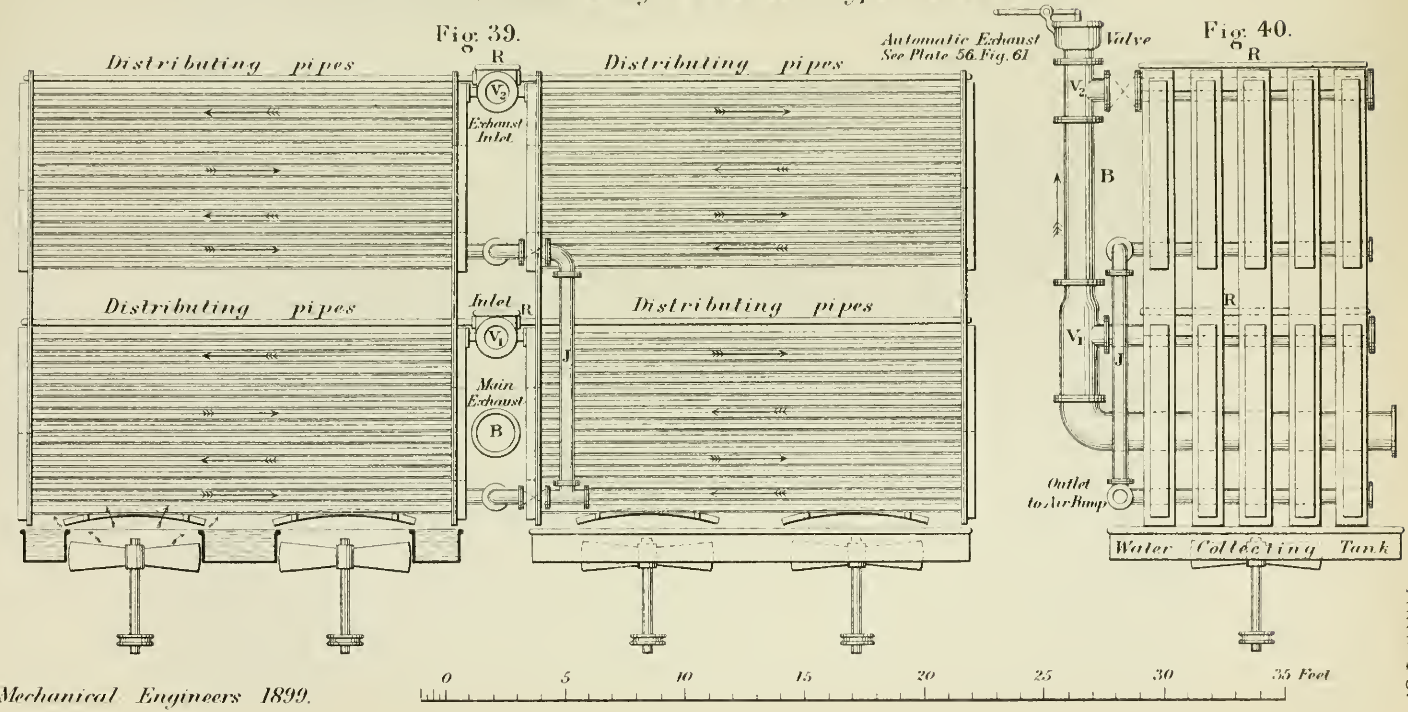
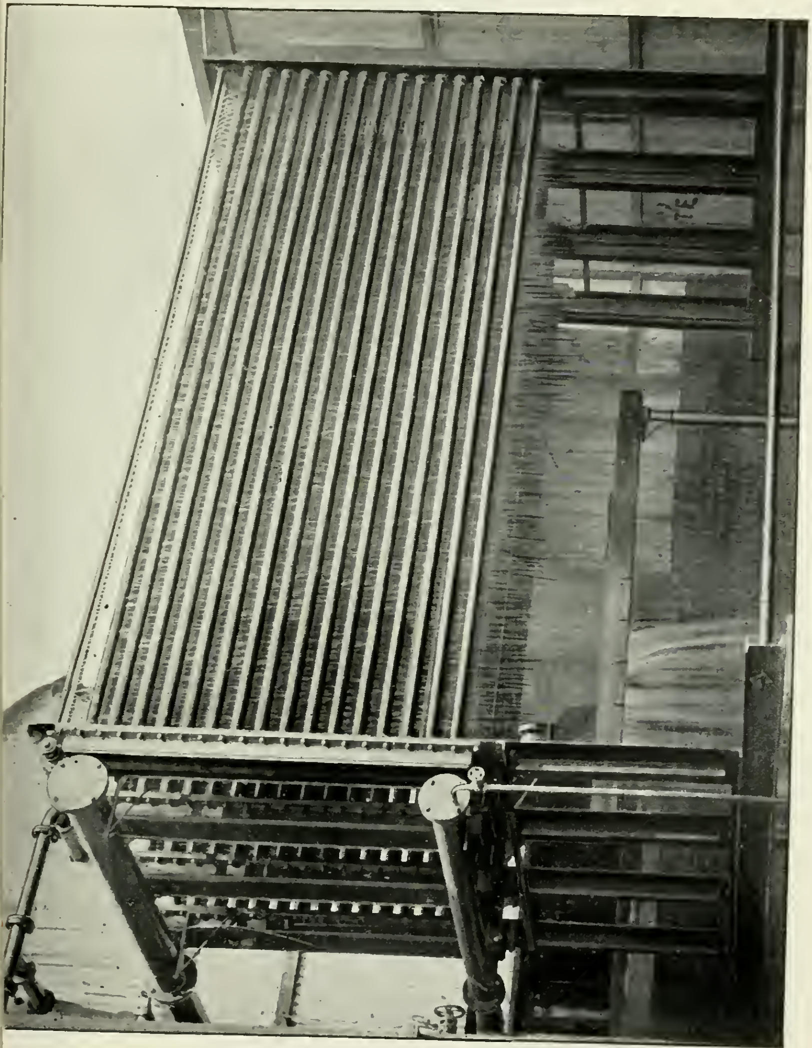


Fig. 41.

Fraser Horizontal Type at Blackpool showing Water circulating over Tubes.



EVAPORATIVE CONDENSERS.

Fraser Vertical Brass-tube Type. Blackpool.

Fig. 42.

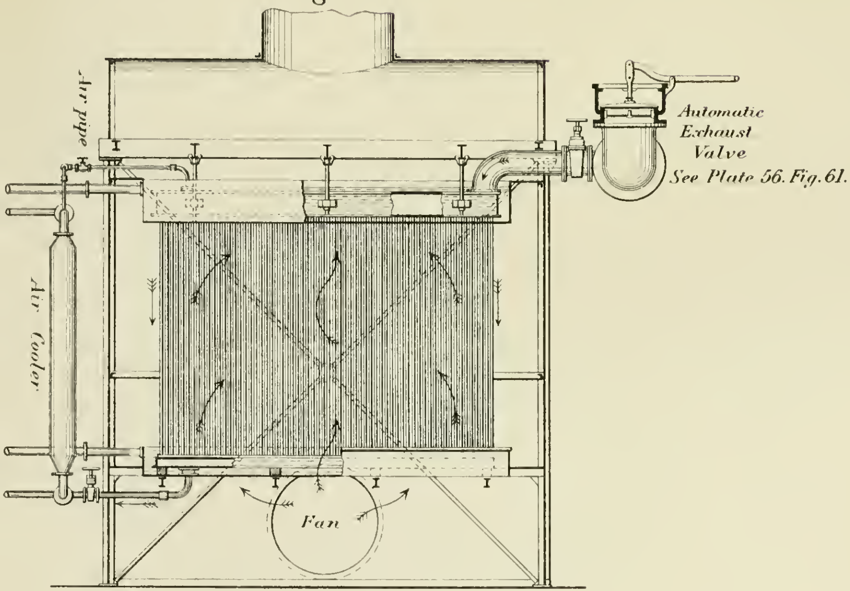
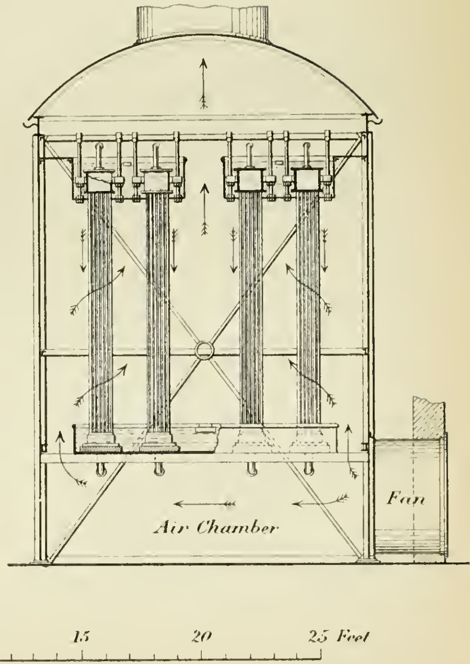


Fig. 43.



EVAPORATIVE CONDENSERS.

Circular Types.

Fig. 44. *Fraser.*

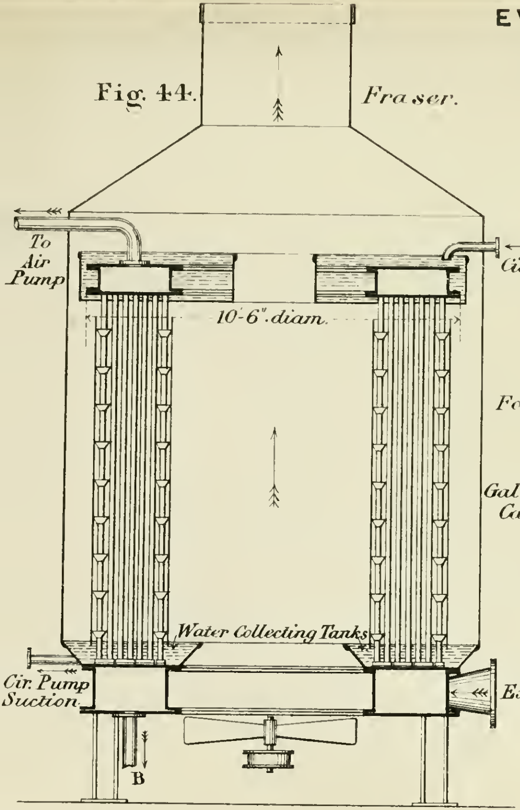
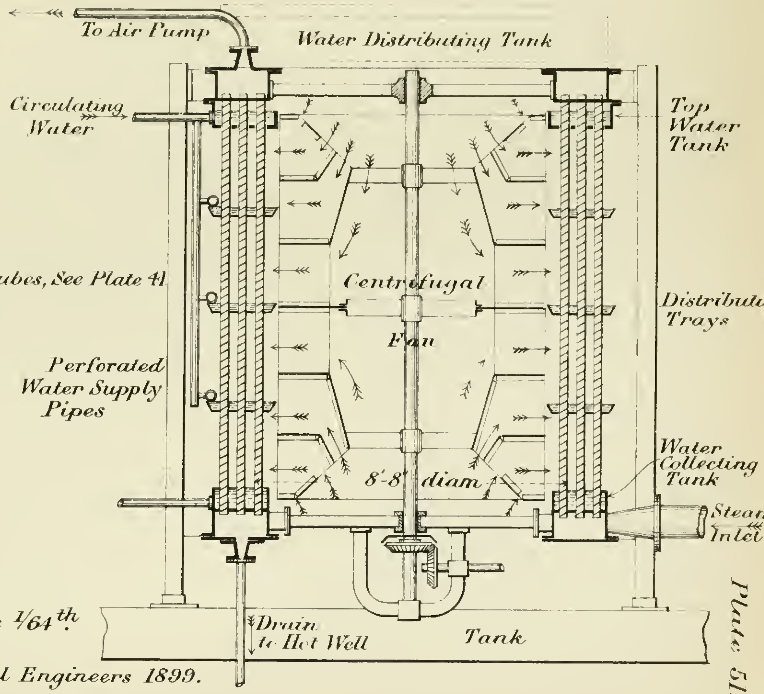


Fig. 45. *Theisen.*



For Details of Tubes, See Plate 41

Scale 1/64th.

Mechanical Engineers 1899.

Plate 51.

EVAPORATIVE CONDENSERS.

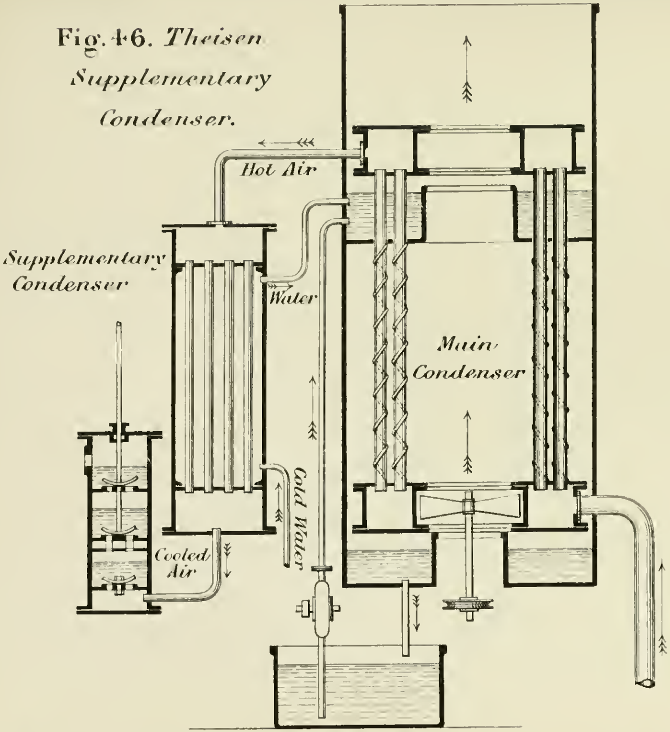


Fig. 46. Theisen Supplementary Condenser.

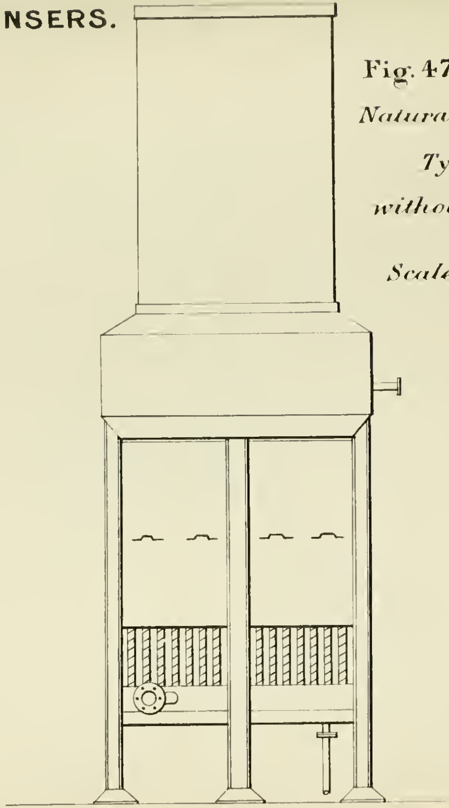


Fig. 47. Theisen Natural Draught Type, without fan.

Scale 1/64th.

Plate 52.

EVAPORATIVE CONDENSERS.

Wright Vertical Brass-tube Type for 500 H.P.

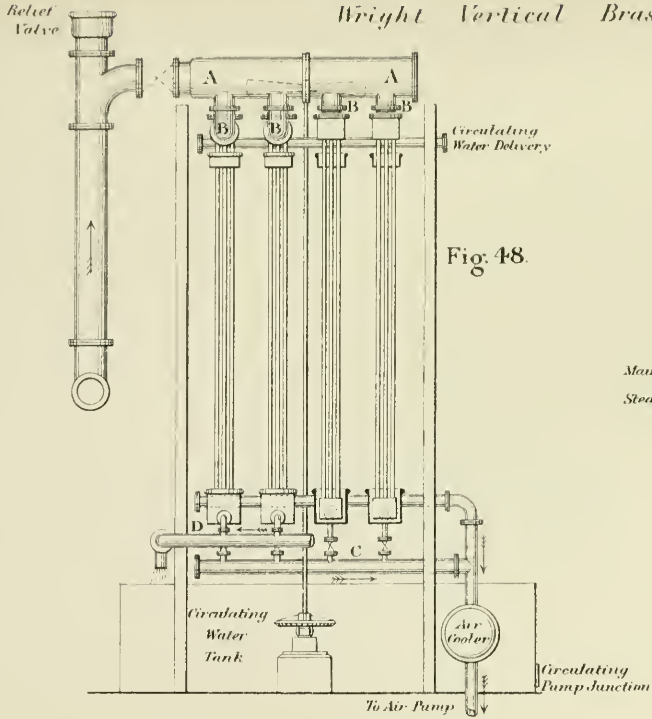


Fig. 48.

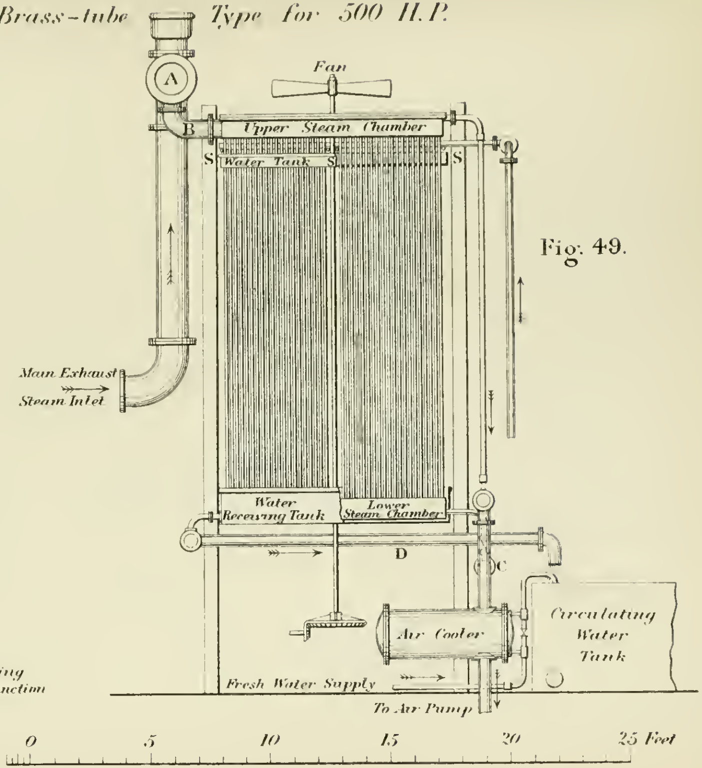


Fig. 49.

Plate 53.

EVAPORATIVE CONDENSERS.

Comparative Methods of leading water over Tubes.

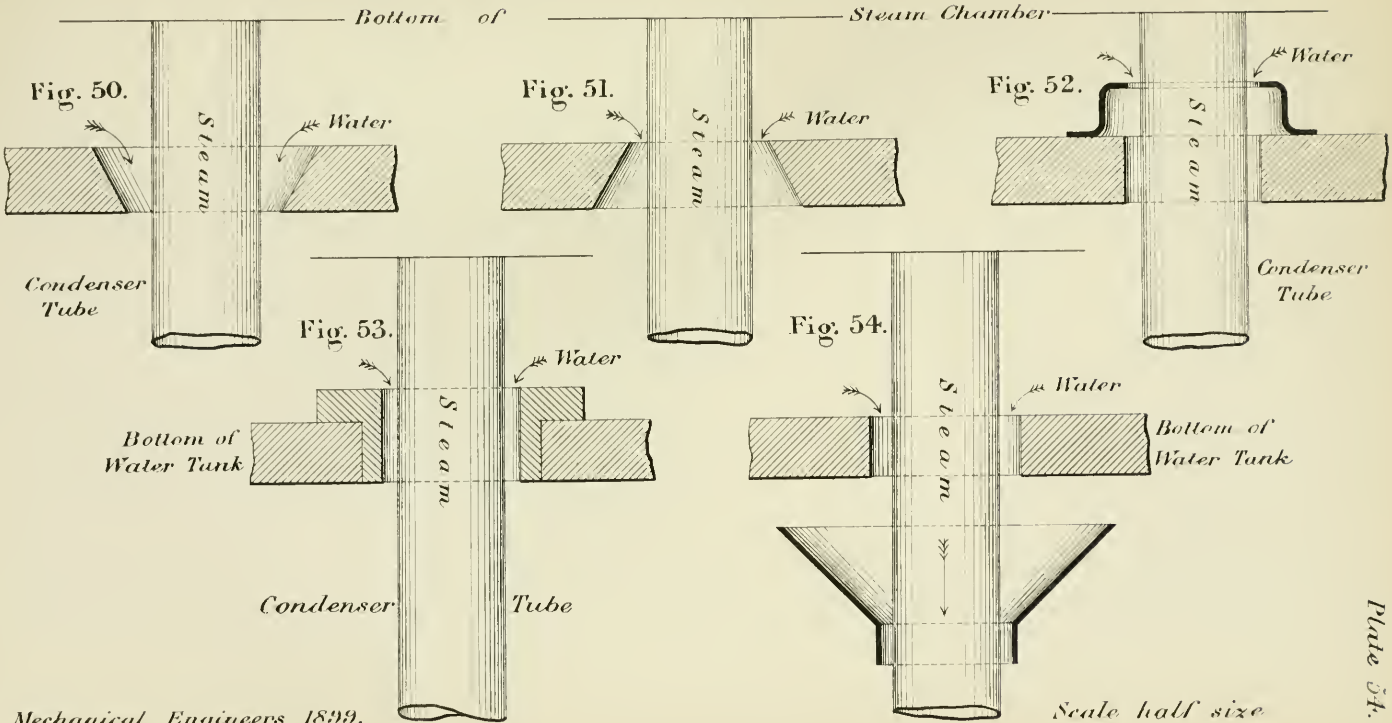


Plate 54.

EVAPORATIVE CONDENSERS.

Horizontal Wrought-iron-tube Condenser. Erected about 1872 in Lambeth.

Fig: 55.

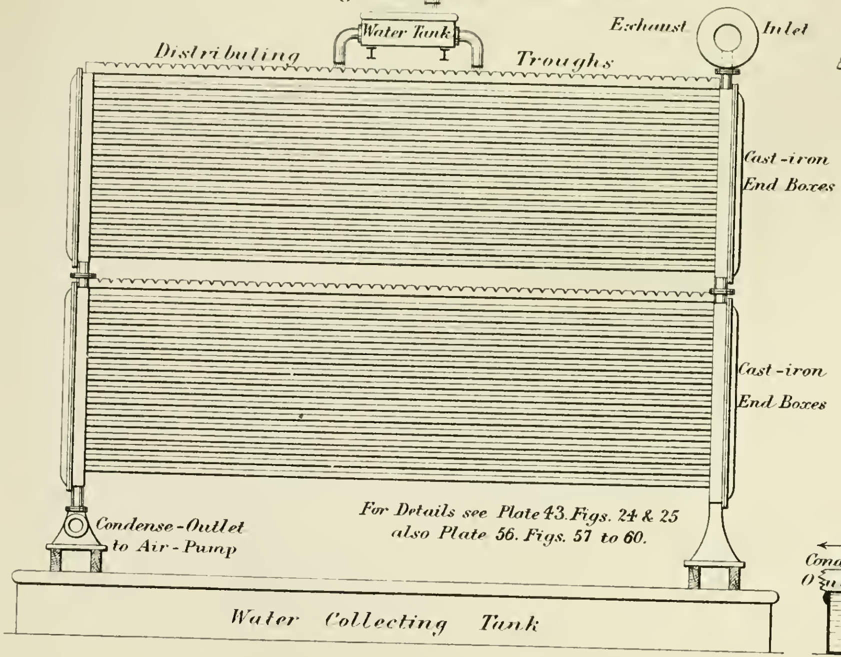
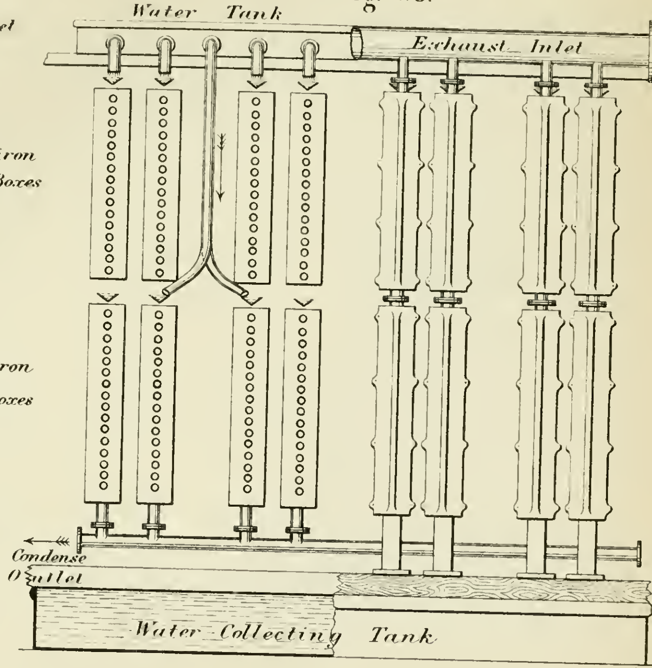


Fig: 56.



Scale 1/48th.

EVAPORATIVE CONDENSERS.

Distributing Trough, see Figs. 55 *and* 56.

Fig. 57.

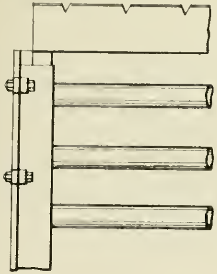
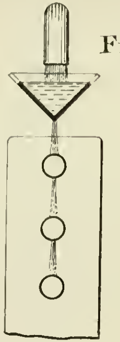


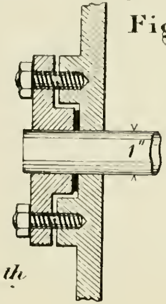
Fig. 58.



Rubber Joint, see Figs. 55 *and* 56.

Fig. 59.

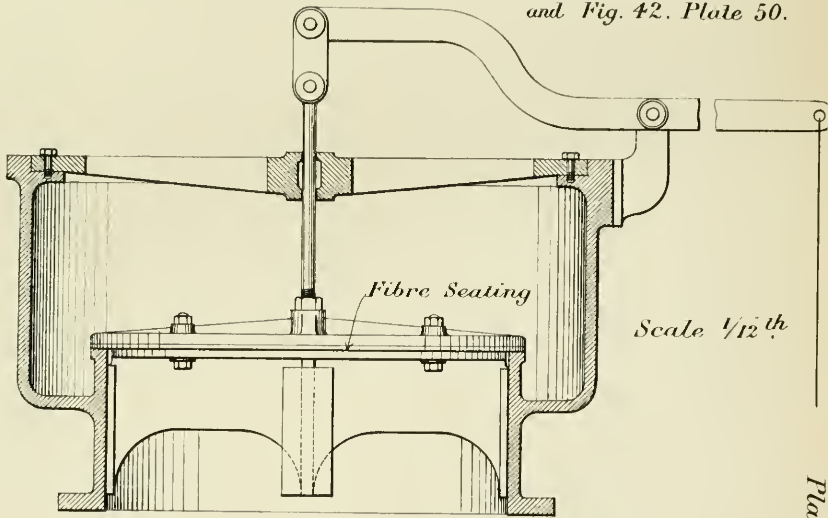
Fig. 60.



Scale 1/4 *th.*

Fig. 61.

Automatic Exhaust Valve, see Fig. 40. *Plate* 48, *and Fig.* 42. *Plate* 50.



Scale 1/12 *th.*

Mechanical Engineers 1899.

EVAPORATIVE CONDENSERS.

Kirkaldy Horizontal Wrought-iron-tube Type.

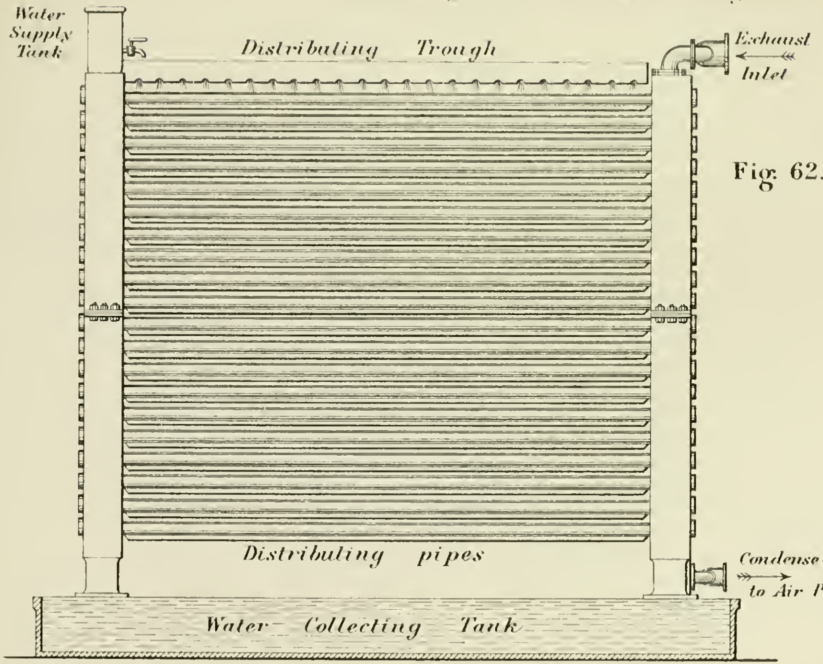


Fig. 62.

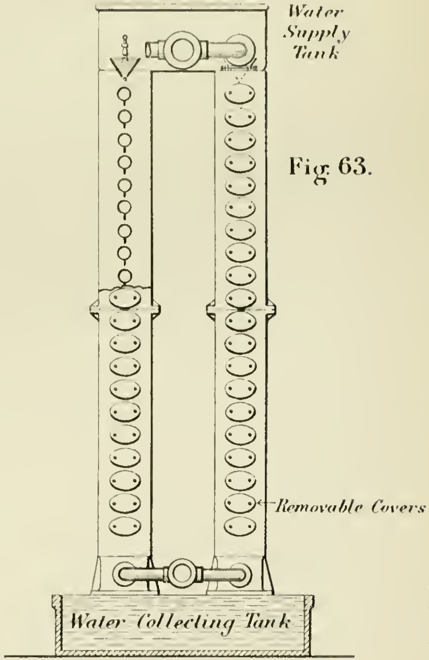


Fig. 63.

Mechanical Engineers 1899.

Scale 1/48th.

Plate 57.

Vertical cast-iron-tube Type.

Fig. 64.

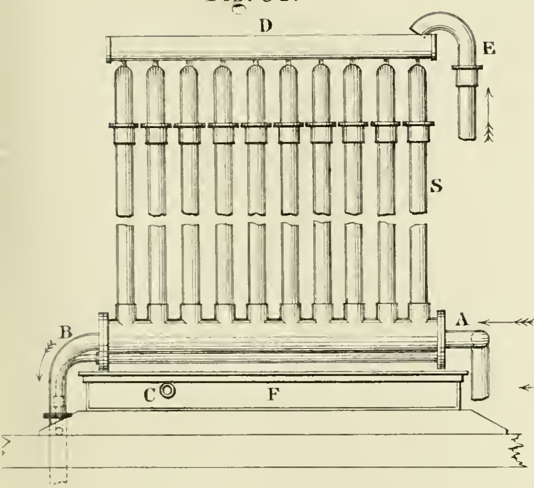


Fig. 65.

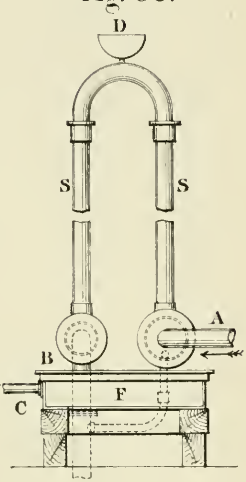
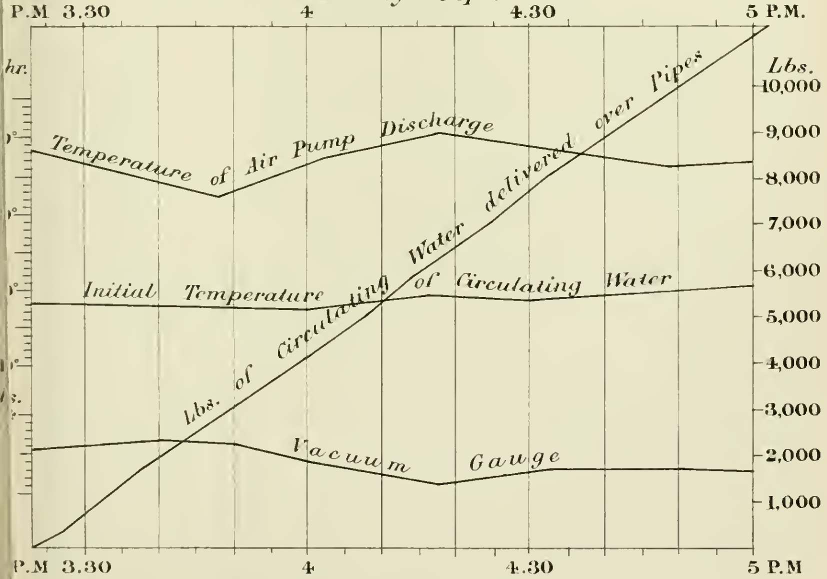


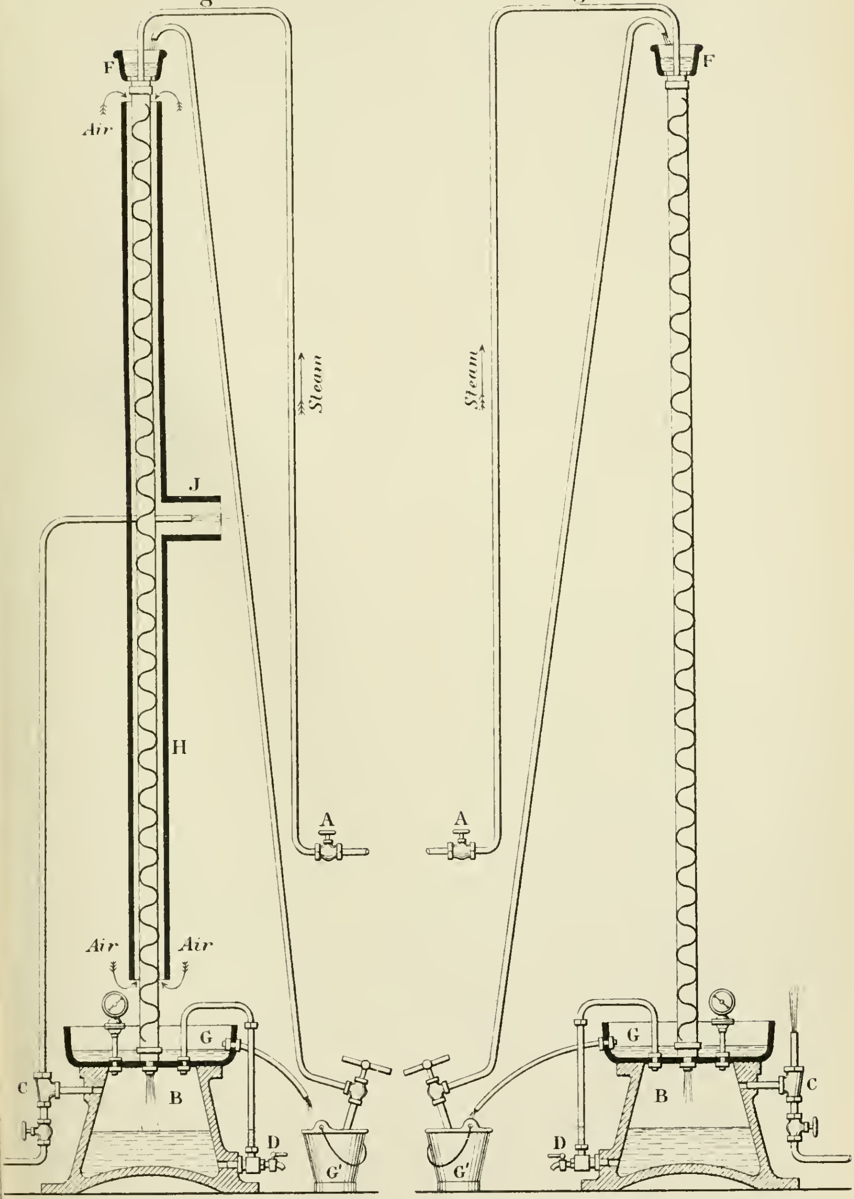
Fig. 66. *Results obtained from above Condensers. on a wet day Sept. 12th.*



Mechanical Engineers 1899.

Row Condenser.

Fig. 67. Fig. 68.



Row Condenser.

For Detail, see Plate 41. Figs. 7 and 8.

Fig: 69.

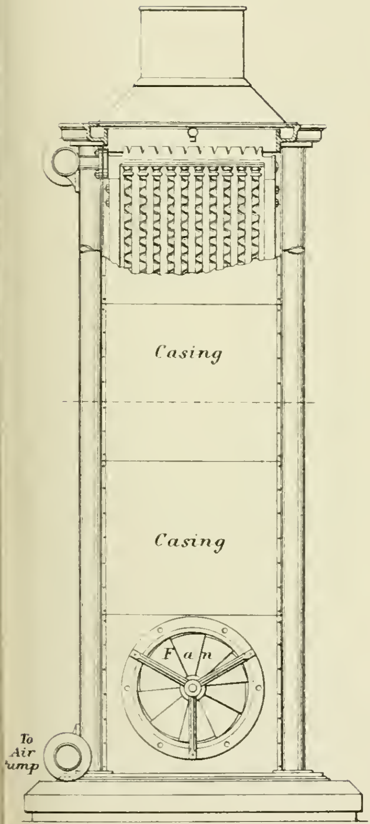
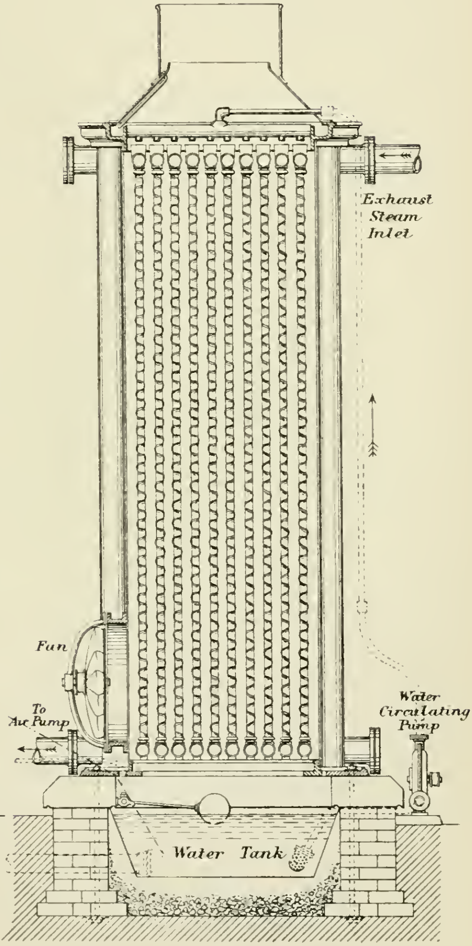


Fig: 70.



Scale 1/48th

EVAPORATIVE CONDENSERS.

Diagrams of Forced and Induced Air Circulation.

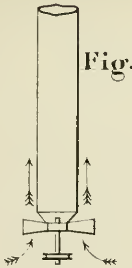


Fig. 71.

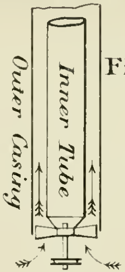


Fig. 72.

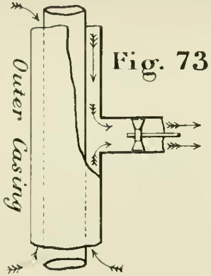


Fig. 73.

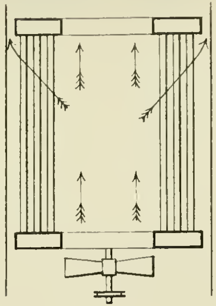


Fig. 74.

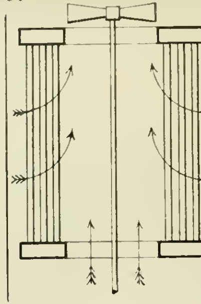


Fig. 75.

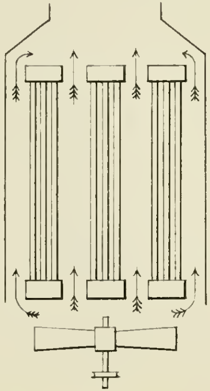


Fig. 76.

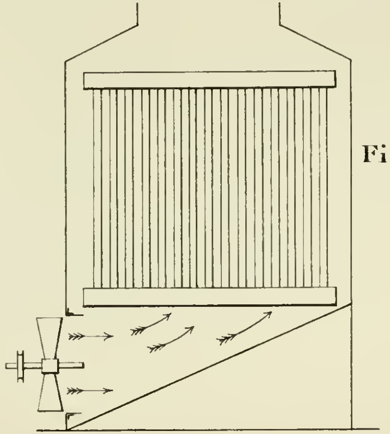


Fig. 77.

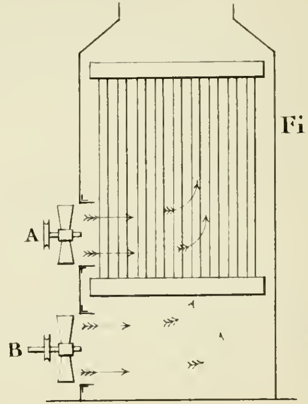


Fig. 78

Plate 61.

EVAPORATIVE CONDENSERS.

Diagram of General Arrangement of Condenser.

Fig. 79.

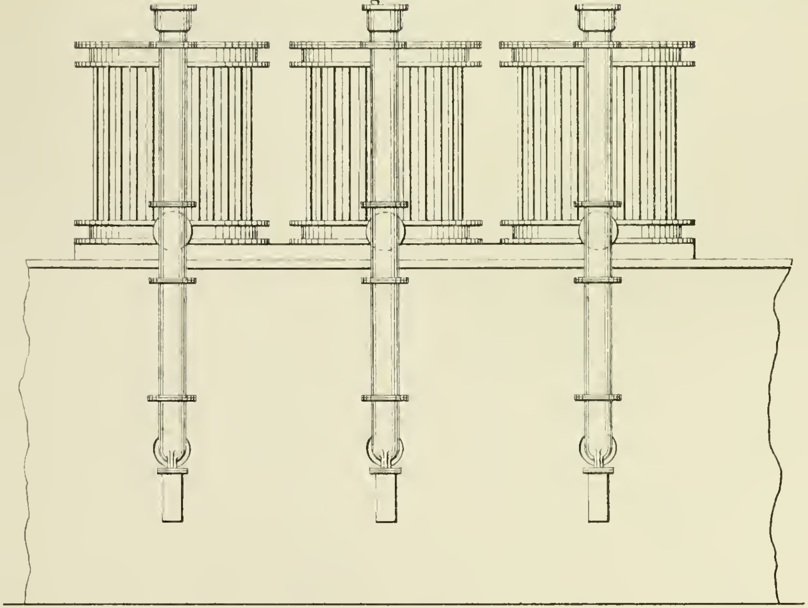


Fig. 80.

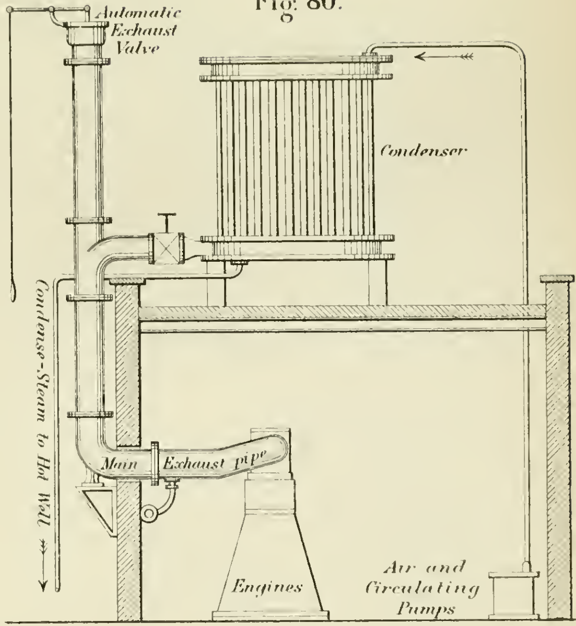


Plate 62.

Kynoch Tube.

Fig: 81.

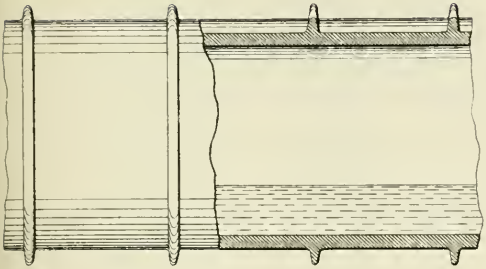


Fig: 82.

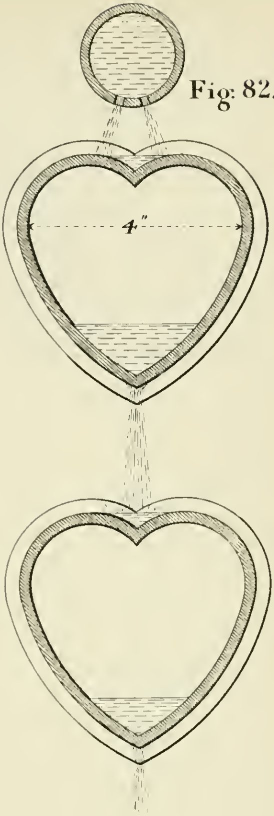
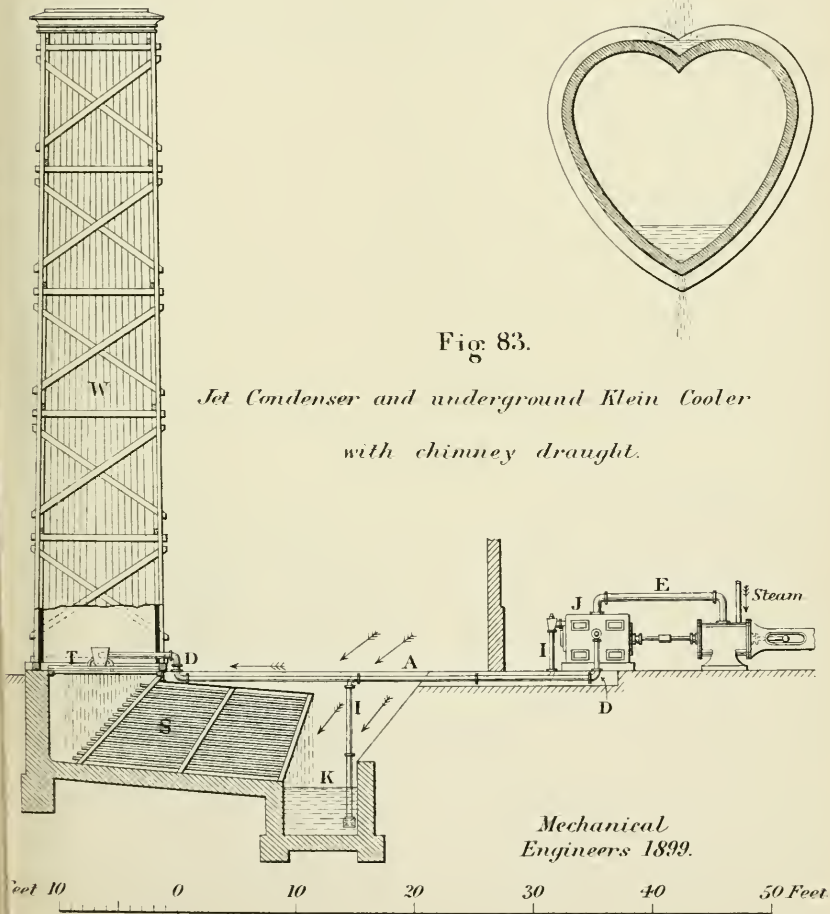


Fig: 83.

Jet Condenser and underground Klein Cooler

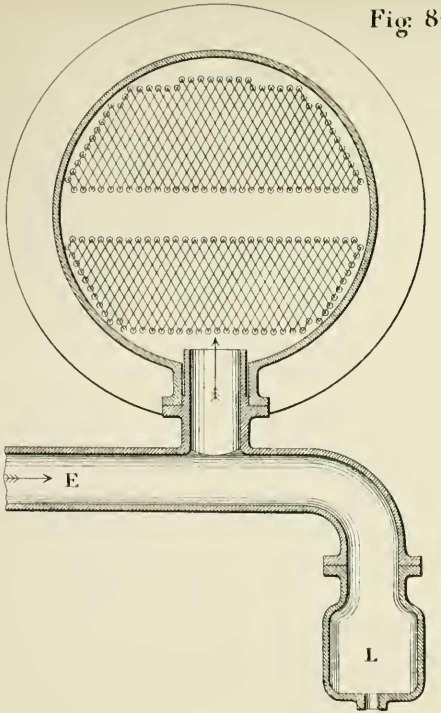
with chimney draught.



Mechanical Engineers 1899.

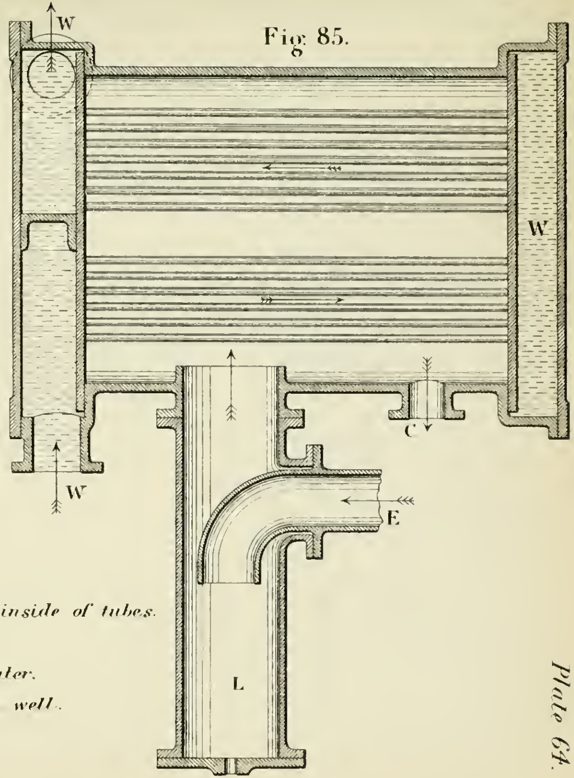
EVAPORATIVE CONDENSERS.

Fig: 84.



Arrangements for collecting waste oil.

Fig: 85.



W = *cooling water flowing through inside of tubes.*
E = *exhaust steam from engine.*
L = *well for catching oil and water.*
C = *condensed steam flowing to hot well.*

Plate 64.

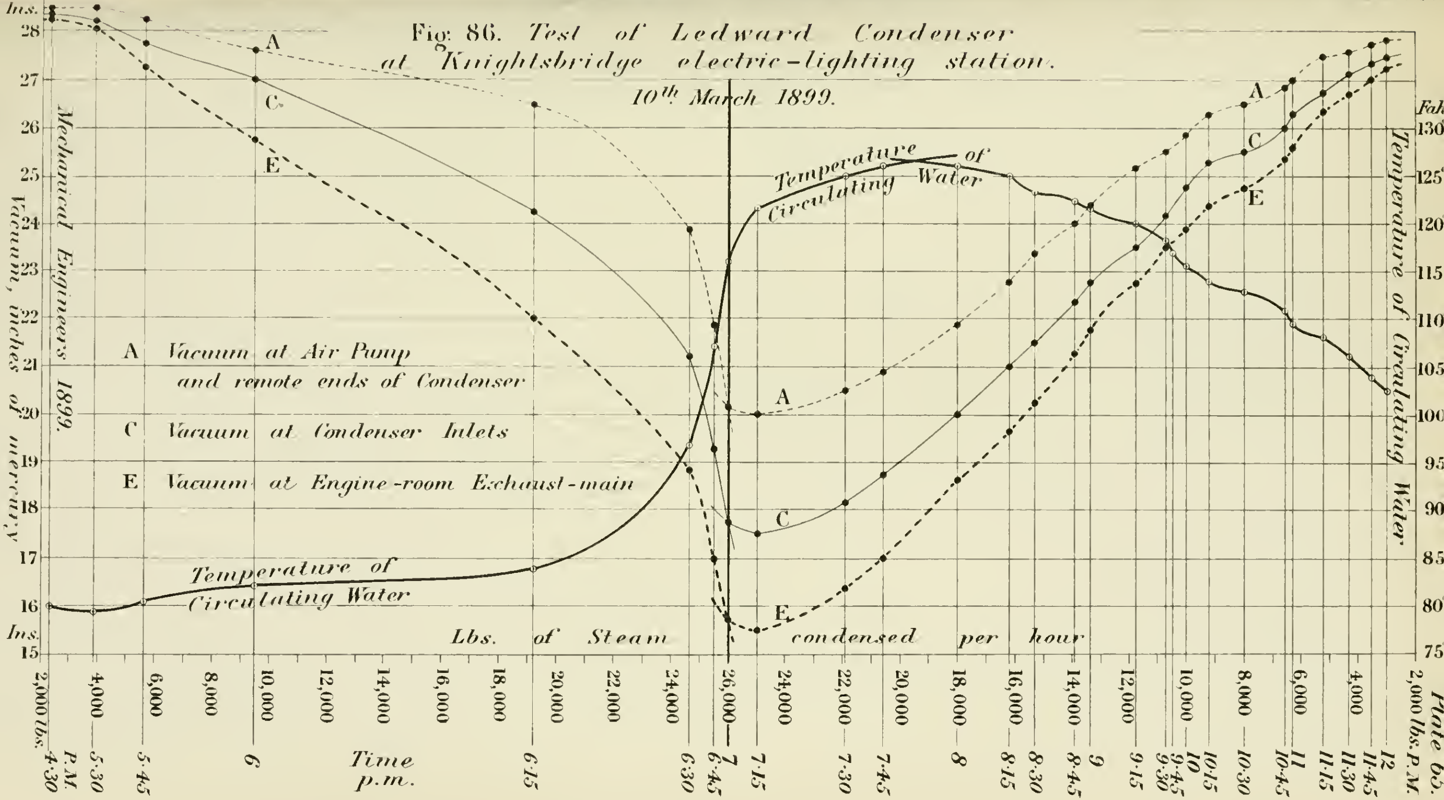


Fig: 86. *Test of Ledward Condenser at Knightsbridge electric-lighting station. 10th March 1899.*

Ammonia and Steam Condenser.

Fig. 87. *Elevation.*

For Side Elevation see Plate 67.

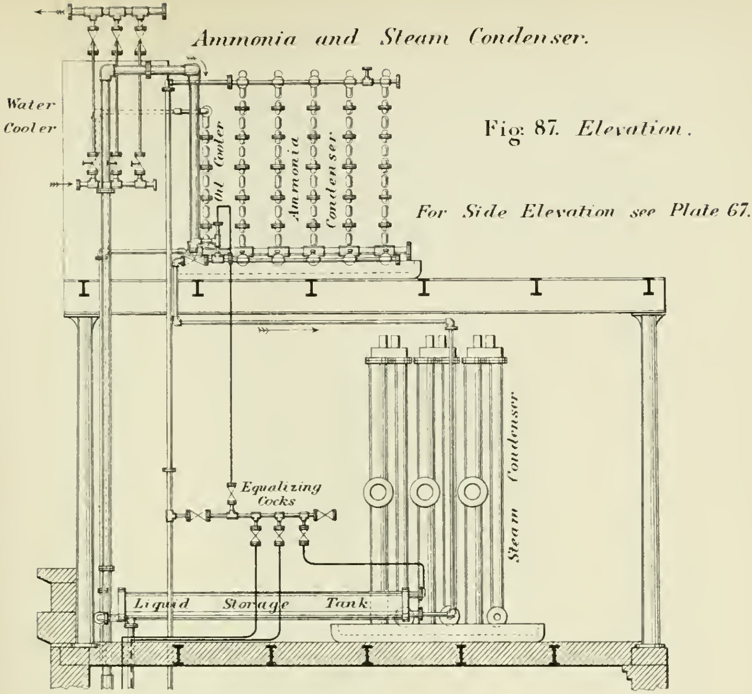
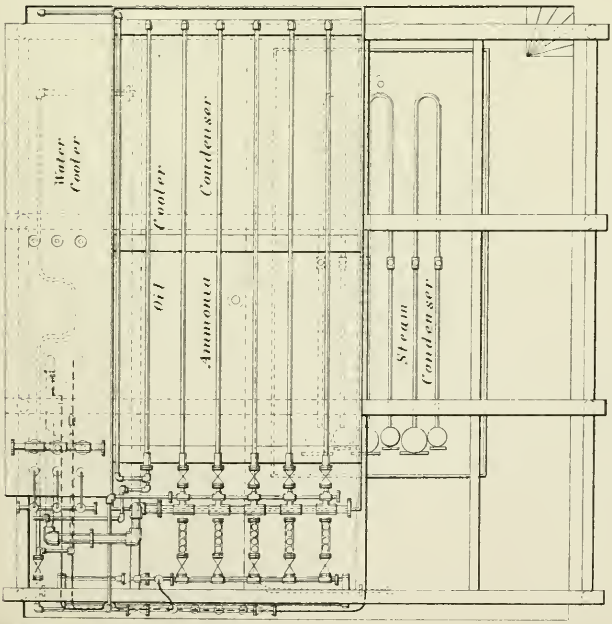


Fig. 88. *Plan.*



 Scale 1/96th.

Ammonia and Steam Condenser.

Fig: 89. *Side Elevation.*

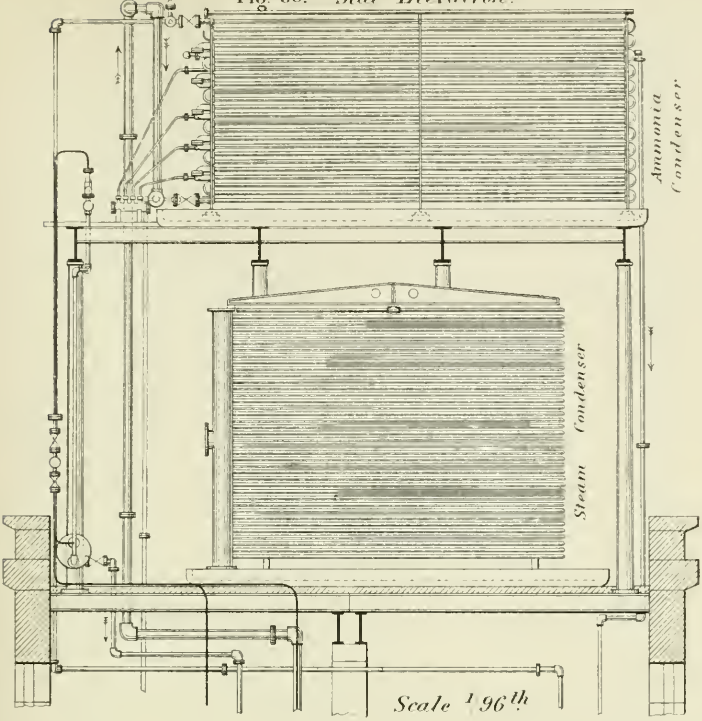
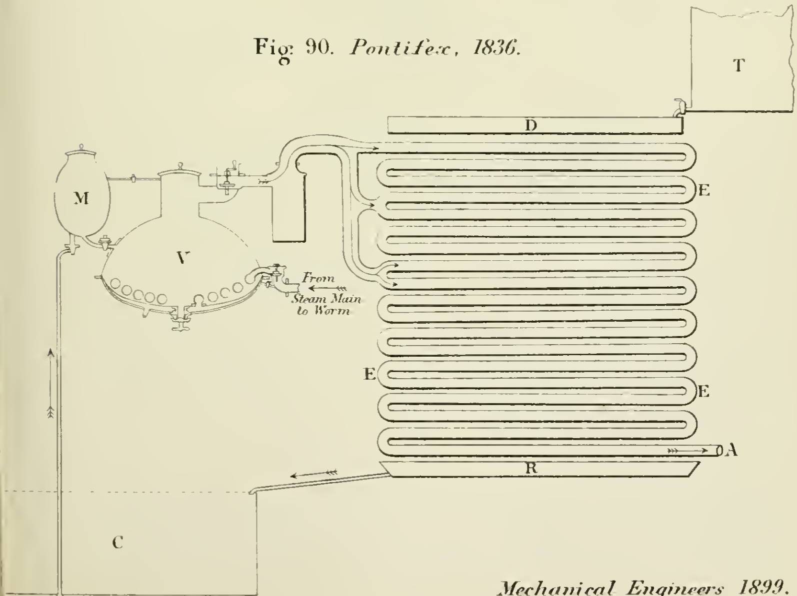


Fig: 90. *Pontifex, 1836.*



Cochrane Condenser.

Fig: 91.

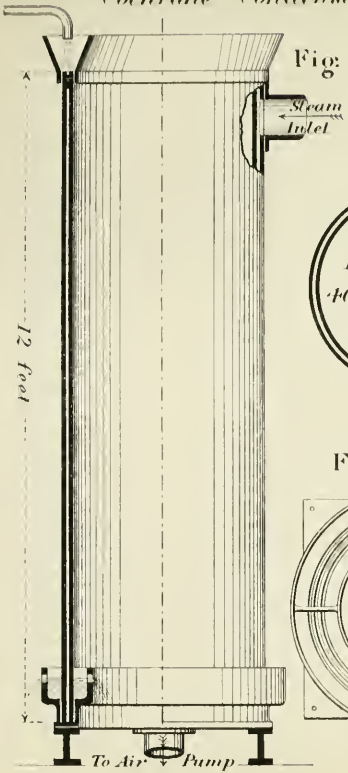
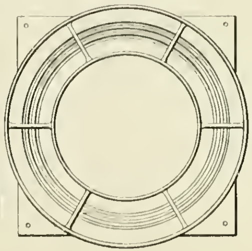


Fig: 92. Section.

Fig: 93. Plan.



Murray Condenser.

Fig: 94.

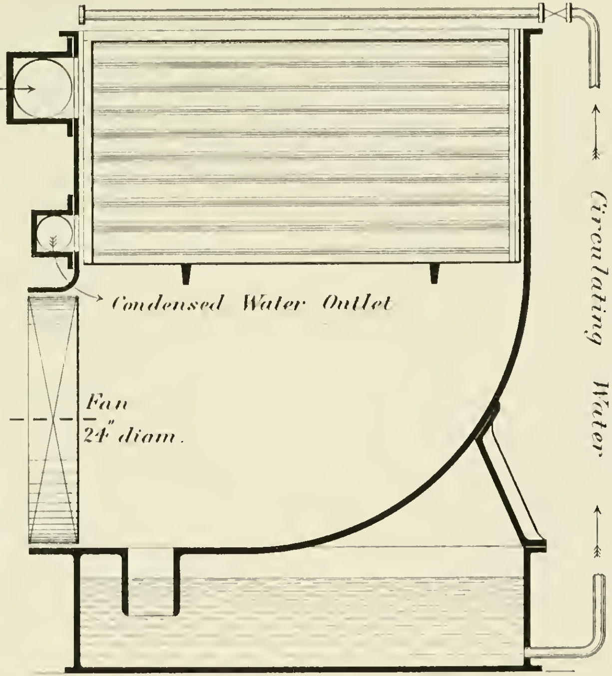


Fig: 95.

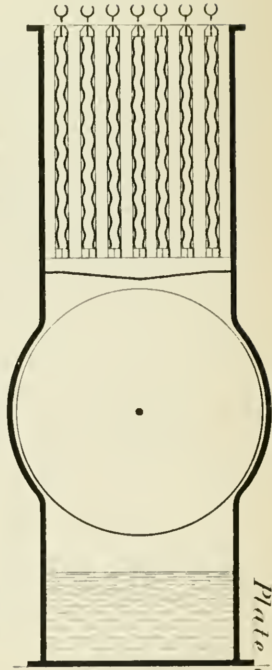


DIAGRAM OF PROGRESS.

From Commencement.

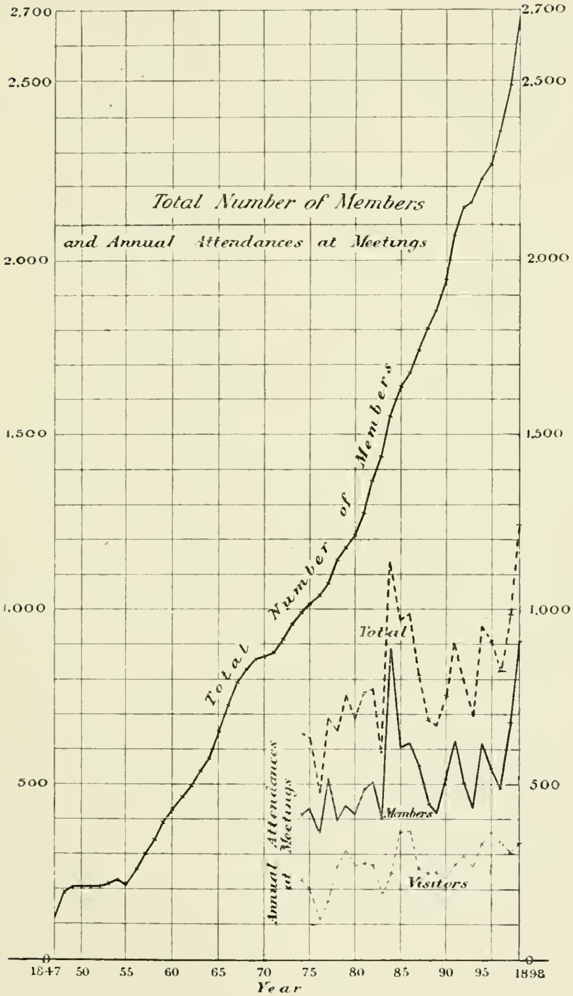
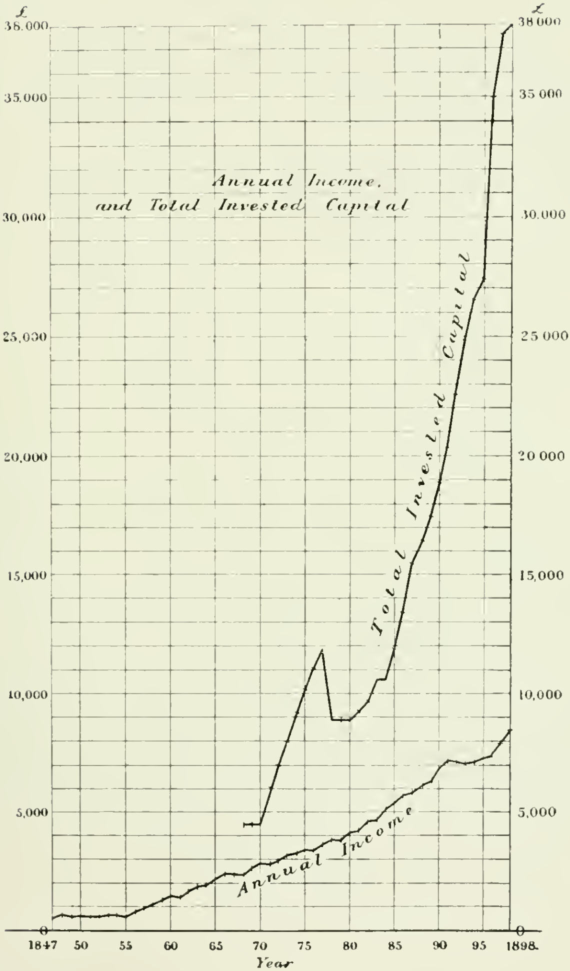


DIAGRAM OF PROGRESS.

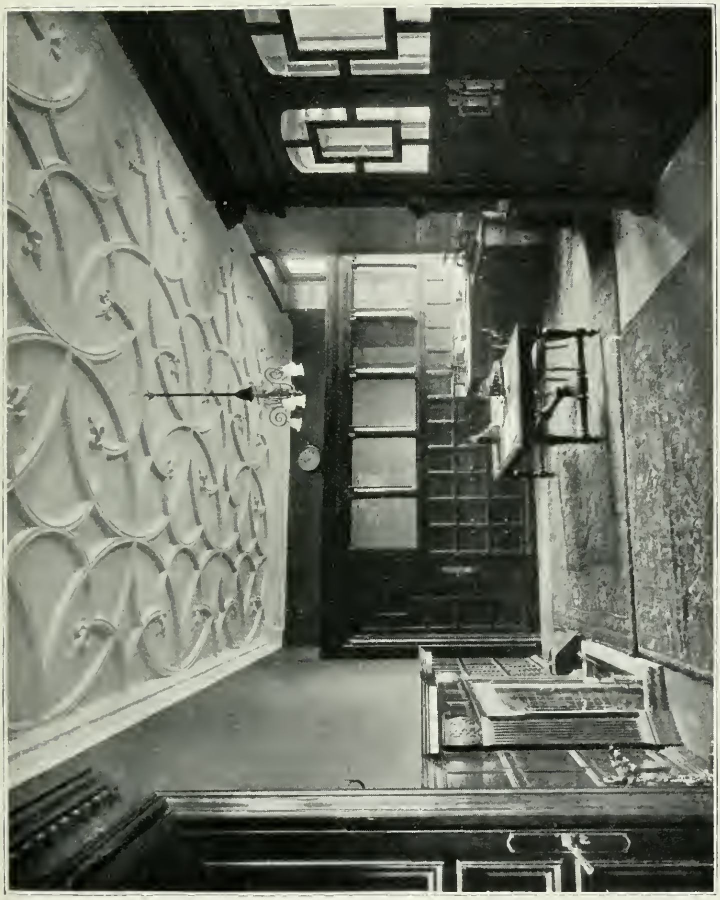
From Commencement.



EXTERIOR OF BUILDING.

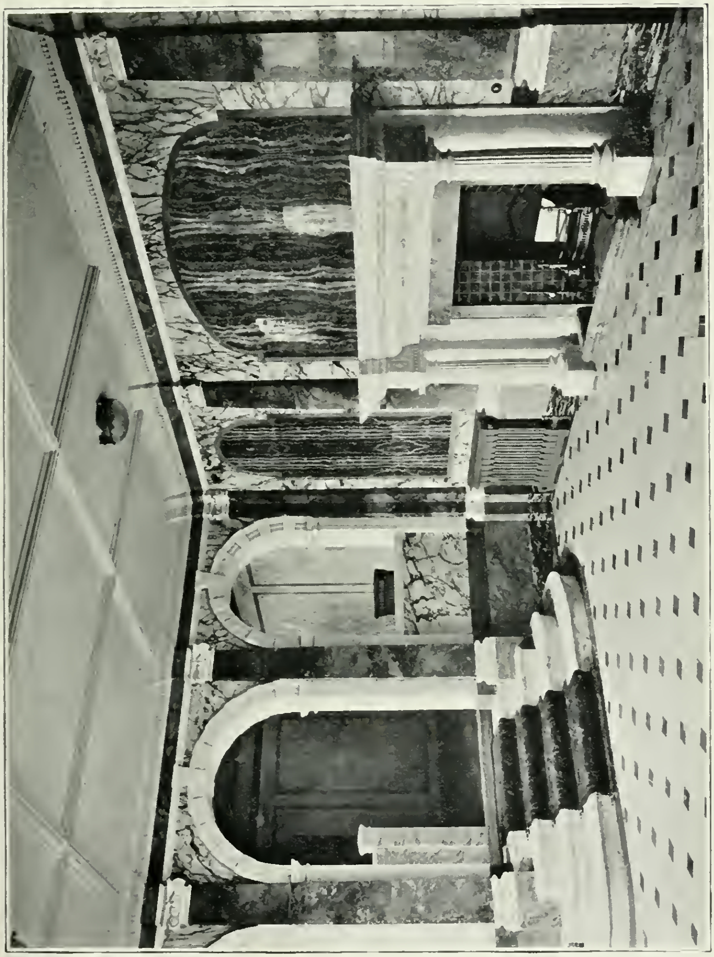
(Taken from St. James's Park.)

EXTERIOR OF BUILDING.
(Taken from St. James's Park.)

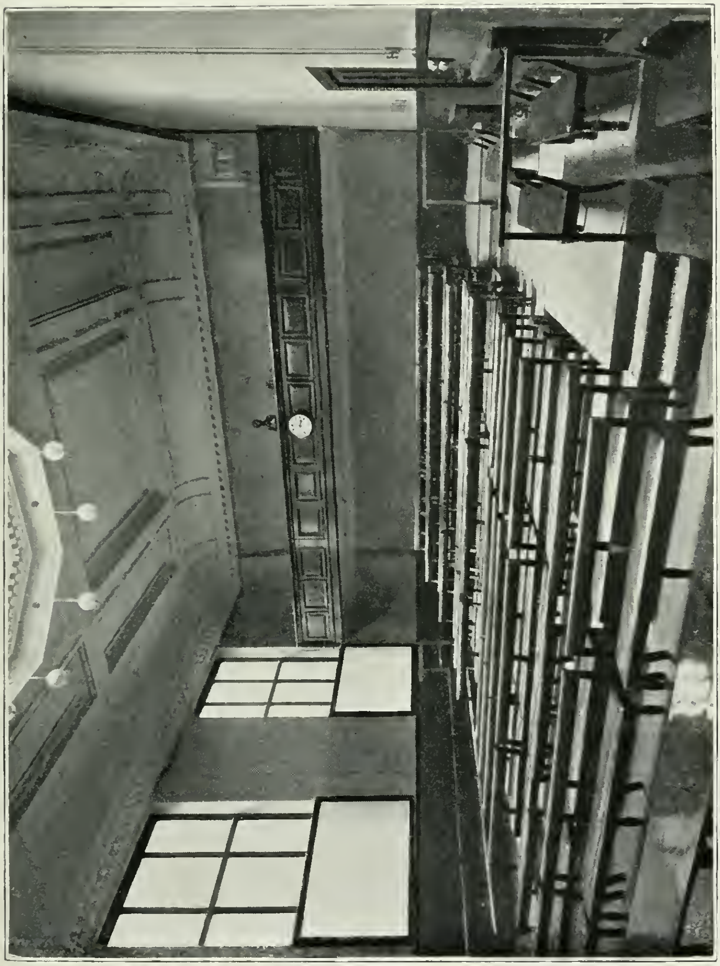


ENTRANCE HALL.
(Looking West.)

TEA ROOM.
(Entresol.)

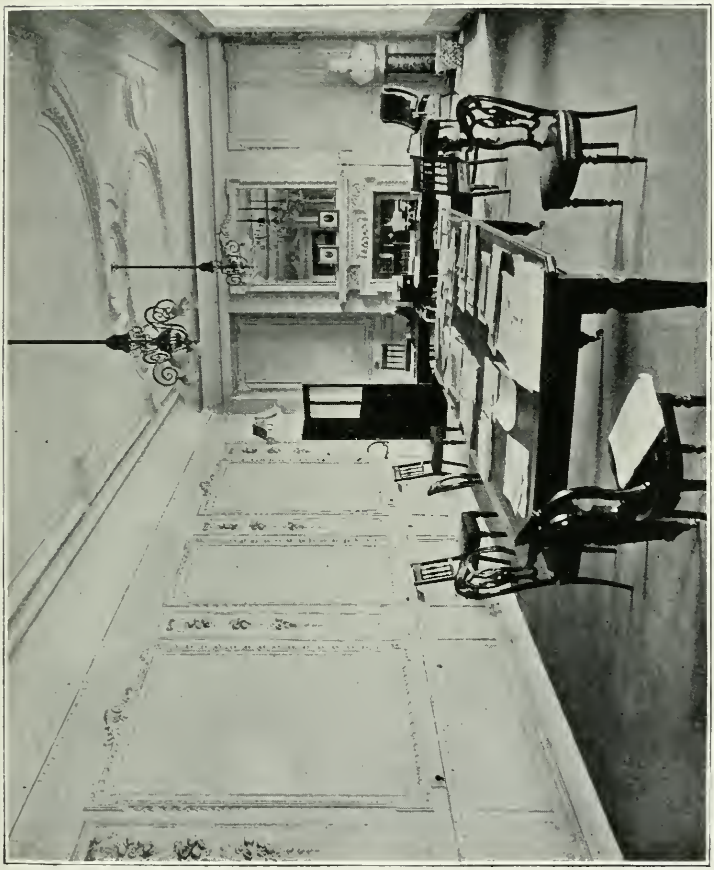


TEA ROOM.
(Entresol.)



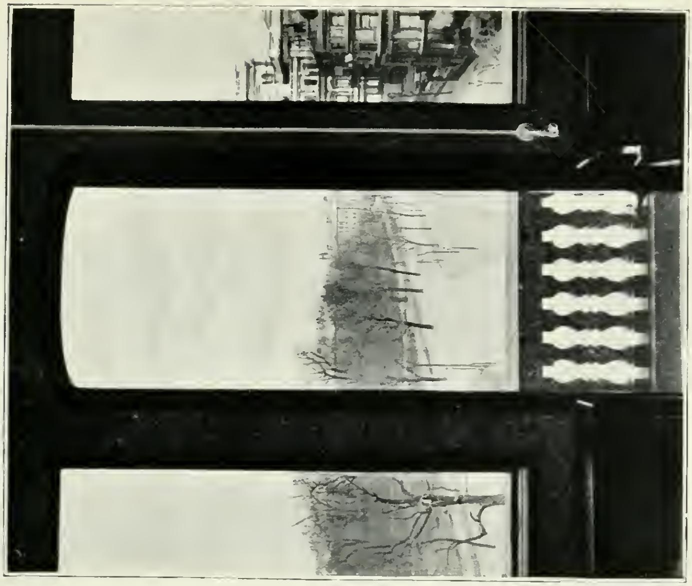
MEETING HALL.
(Ground Floor.)

COUNCIL ROOM.
(Ground Floor.)

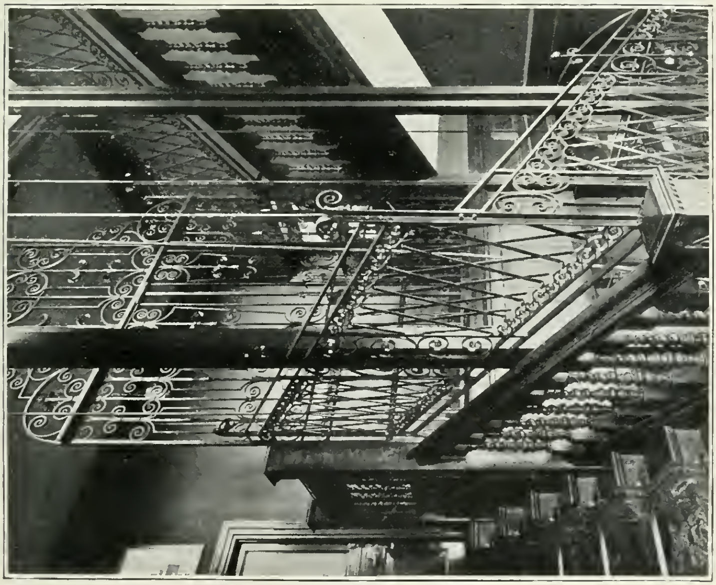


READING ROOM
(Mezzanine)

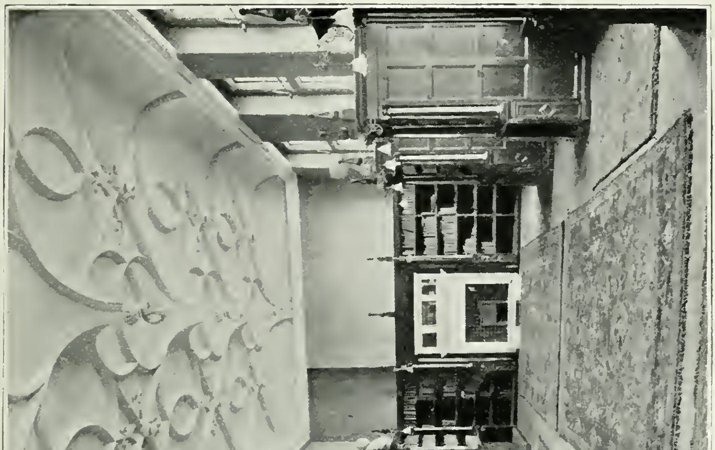
Mechanical Engineers 1899.



VIEW FROM LIBRARY WINDOW.



STAIRCASE.



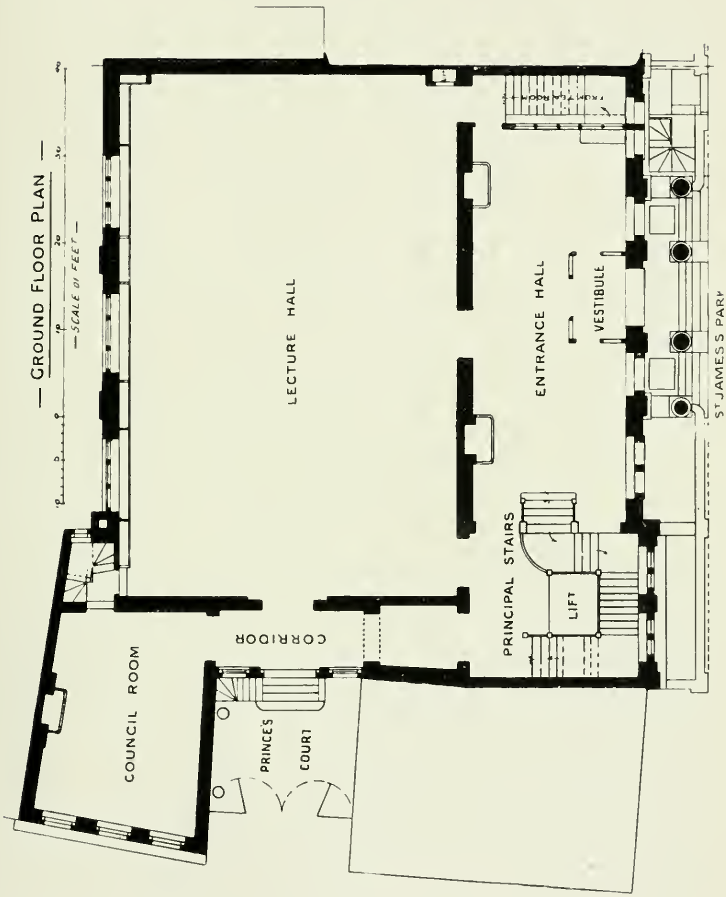
LIBRARY.
(*First Floor.*)

WESTERN ANNEXE OF LIBRARY.
(First Floor.)

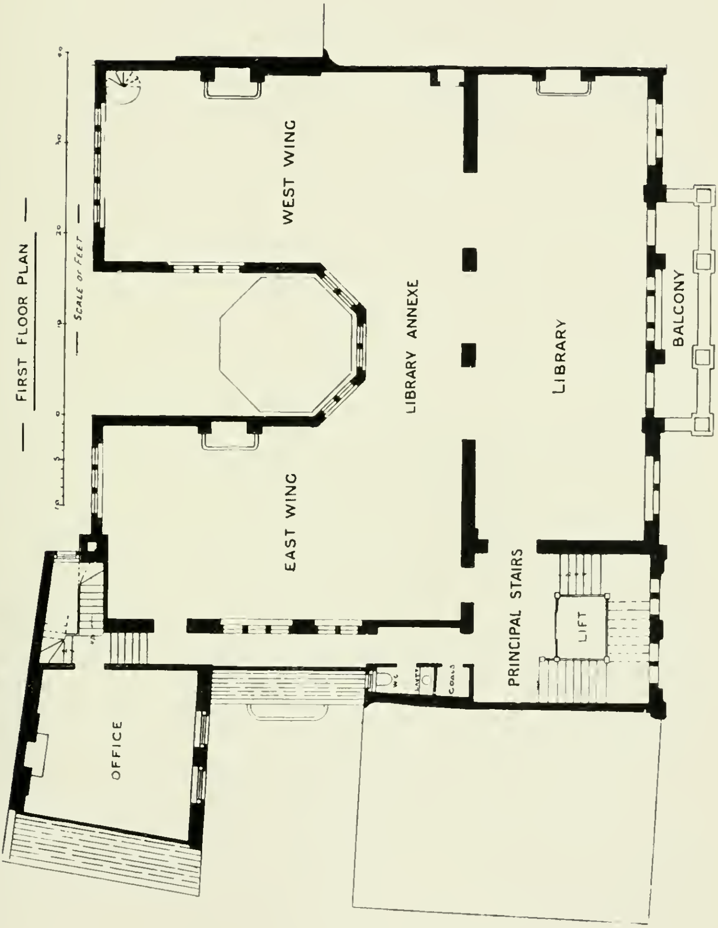
DRAWING OFFICE.

(Third Floor.)

GROUND FLOOR.



FIRST FLOOR.


FIRST FLOOR PLAN
SCALE OF FEET
WEST WING
EAST WING
LIBRARY ANNEXE
LIBRARY
BALCONY
PRINCIPAL STAIRS
LIFT
OFFICE
COALS

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OF

MECHANICAL ENGINEERS.

ESTABLISHED 1847.

PROCEEDINGS.

1899.

Parts 3–4.

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Percy G. B. Westmacott, ... Ascot.

VICE-PRESIDENTS.

Arthur Keen, ... Birmingham.
Edward P. Martin, ... Dowlais.
William H. Maw, ... London.
T. Hurry Riches, ... Cardiff.
A. Tannett Walker, ... Leeds.
J. Hartley Wicksteed, ... Leeds.

MEMBERS OF COUNCIL.

Sir William Arrol, M.P., LL.D., ... Glasgow.
John A. F. Aspinall, ... Manchester.
Sir Benjamin Baker, K.C.M.G., LL.D., F.R.S., ... London.
Henry Chapman, ... London.
Henry Davey, ... London.
William Dean, ... Swindon.
Bryan Donkin, ... London.
Edward B. Ellington, ... London.
H. Graham Harris, ... London.
Henry Lea, ... Birmingham.
John G. Mair-Rumley, ... London.
Henry D. Marshall, ... Gainsborough.
The Right Hon. William J. Pirrie, LL.D. .... Belfast.
Sir Thomas Richardson, M.P., ... Hartlepool.
John I. Thornycroft, F.R.S., ... London.

TREASURER.

Harry Lee Millar.

SECRETARY.

Edgar Worthington,

The Institution of Mechanical Engineers, Storey's Gate, St. James's Park, Westminster, S.W.

Telegraphic address:—*Mech, London.* Telephone:—*Westminster*, 264.

The Institution of Mechanical Engineers.

PROCEEDINGS.

JULY 1899.

The SUMMER MEETING of the Institution was held in Plymouth, commencing on Tuesday, 25th July 1899, at Ten o'clock a.m.; Sir WILLIAM H. WHITE, K.C.B., LL.D., D.Sc., F.R.S., President, in the chair.

The President, Council, and Members were received in the Guildhall by the Worshipful the Mayor of Plymouth, Alderman JOHN PETHICK; by the Worshipful the Mayor of Devonport, WILLIAM HORNBROOK, Esq.; and by the Chairman of the East Stonehouse Urban District Council, JOHN E. BONE, Esq., J.P.

The MAYOR OF PLYMOUTH said it gave him the greatest pleasure to welcome the members, and if there was one thing more than another which increased that pleasure it was the fact that the President of the Institution was a native of a sister town, Devonport. He expressed the hope that the members would be favoured with fine weather during their stay in the historic borough, and that they would take the opportunity of visiting the many charming and picturesque spots with which Plymouth abounded, particularly the rivers Plym, Lynher, Tamar, Dart, and Yealm. The inhabitants of Plymouth prided themselves on having one of the finest harbours in Europe, a harbour land-locked, with plenty of deep water, and a breakwater which was a triumph of engineering skill. The engineering works which had been carried out in the neighbourhood, especially the erection of the Eddystone lighthouse, were matters of which the

(The Mayor of Plymouth.)

town was very proud. He thought the members in looking over the Keyham works, for which no doubt they had supplied a great deal of machinery, would admit that they were unrivalled in the country, and a credit to the Admiralty officials and to Sir John Jackson who had the work in hand. He hoped the members would pay particular attention to Plymouth Harbour. Plymouth was not like some of the manufacturing districts with only one railway and canal supplies. It had a port second to none, and he hoped that the visit of the Mechanical Engineers would be the means of giving an impetus to further enterprise, and result in the starting of works in the harbour such as it was worthy of. No place could be more worthy of such works. Coal was not far distant, and every other commodity was readily available. Inland places which carried on large manufacturing industries had not the facilities which Plymouth possessed. In conclusion, his worship declared that he felt it a great privilege to be able to welcome such a body as the Mechanical Engineers, and congratulated the President on the position he had reached by his own energy and integrity.

The MAYOR OF DEVONPORT, on behalf of that borough, also accorded the members the heartiest possible welcome. They welcomed them because of the inestimable value of the work which Mechanical Engineers had to perform, and as representatives of a grand Institution which had done probably more than any other Institution for the advancement of science and for the amelioration of mankind. To the engineer had been given the privilege of unfolding the mysteries of science; and science, through her gifted sons, had laid bare her richest treasures. It was the engineer who tunnelled the mountains of Switzerland, and built railways on a gradient of 55 in 100; who, metaphorically speaking, reduced the towering heights of the Rigi and the Pilatus to the level of their feet, and who was slowly bringing the nations of the earth together and encircling the globe with active, living, burning thought. Everyone appreciated what engineers had already done, and they looked forward with expectation—and he was sure they would not be disappointed—to the work which remained to be done and to which the owners of

many an honoured name had already lent their assistance. He congratulated the Institution on having at its head Sir William White, and if he spoke of him as the greatest genius that the century had produced, he was sure the members would not consider him guilty of exaggeration. The Three Towns had watched Sir William's career, and had rejoiced at the great success which he had achieved. Devonport was proud of him, and proud to know that the example he had set would be the lever by which many a poor boy would raise himself to a position of honour and trust. He expressed the hope that the members would thoroughly enjoy themselves, and was sure that they would have no cause to regret their coming to the metropolis of the West.

Mr. J. E. Bone said he had been asked, as representing the East Stonehouse Urban District Council, to support the welcome offered to the Institution, and he was delighted to do so. No words of his could convey the feelings that arose within his mind when he thought of the brain power which was gathered together in that hall. His welcome was as hearty and strong as that extended by the Mayors of Plymouth and Devonport, if not stronger, for he recalled the fact that it was about thirty-seven years ago when he first met Sir William White, who was then leaving Devonport Dockyard for College. At that time he himself was a boy, and Sir William was starting on that career which had led him to such a high and honoured position. In conclusion he trusted that the members would find their visit a recreation after their arduous labours of the past twelve months, and that they would go back with the impression that "bonny Devonshire" was a grand place for relaxation.

The President, on behalf of the Institution, returned the most sincere thanks of the members for the very cordial welcome which had been given by the representatives of the three municipalities. The Institution in its Summer Meetings went far and wide, but it was not often that it held the distinction of being received by two mayors and the chairman of an urban district council. He knew

(The President.)

that there were members of the Institution present so unhappy as not to have been born in Devonshire, and for those gentlemen Devonshire men were all very sorry. He believed there were members present who would be guilty of passing from Plymouth to Stonehouse or Plymouth to Devonport without ever being aware of that fact. But they had the evidence vividly before them that those three towns, which were growing so rapidly, although they might be divided in forms of government, were united in their welcome of the Institution. The home of the Institution was now fixed definitely in London, in that beautiful house of which the members were so proud. But although the headquarters were in London, the members were spread all over the British Empire—it might be said all over the world. They were glad that was so, and also glad that all the meetings need not be held in London, that the practice of having a Summer Meeting away from town was so well established, and that it was certain never to cease. It was not always, though, that the Institution had an opportunity of visiting a district like Plymouth, where in combination with engineering works of the first class there was an opportunity of enjoying the beauties of nature in their most perfect form. Standing on soil rich in historical associations, to look around that beautiful hall, with its windows picturing the deeds of the past, must be an inspiration to all. They were meeting that day under circumstances of great promise. The Papers to be read all more or less bore upon local work. He need not go through the list, but he could not refrain from expressing what he felt was the universal sentiment of all the members, that they welcomed most cordially their friend—he was going to say their patriarch in the profession—Sir Frederick Bramwell. Sir Frederick was going to tell the story of an engineering enterprise which was carried out in the district of South Devon, the story of the Amospheric Railway; a story in some senses of failure, in others of achievement, but a story which Sir Frederick could speak of as very few living men could do. There were also Papers dealing with the work of that great Arsenal which the members hoped to visit; and Papers dealing with that great engineering work which had been done under the advice of a

member of the Institution, Mr. Mansergh, for largely increasing the water supply of Plymouth. He was sure that as the members visited the various works thrown open to them by the courtesy of the proprietors and of the municipalities, there would be nothing but expressions of satisfaction and enjoyment enhanced by the fact that no scar had been brought upon the face of nature by the progress of industry. There were centres of industry where one could not but wonder at what had been achieved, but he was bound to say that one was not sorry to quit them for a purer atmosphere and brighter prospects. There were however dangers of another kind. He never came to the west without feeling that it was a place tending to give rein to pleasure-seeking to an extent which was not done elsewhere. There were ladies with the members, and the temptation would be great to make the pleasurable side of the work very prominent. He begged the members to do all they could to keep the ladies right in that matter, so that they would not go away without feeling that they had profited by the opportunities that had been given them of seeing not merely the beauties of nature but the wonders of engineering. He thanked the Deputation for their welcome, and assured them that the members were very conscious of and grateful for all their kindness and courtesy.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and the following one hundred and eight candidates had been found to be duly elected :—

MEMBERS.

Baguley, Ernest Edwin,	Stafford.
Barker, Gerald,	London.
Bashforth, Andrew,	Sheffield.
Beale, Bertram Robert,	London.

Beeley, Thomas Carter, . .	Manchester.
Biles, John Harvard, . . .	Glasgow.
Blenkinsop, John Nicholas, . .	Harwich.
Capel, Herbert Churchill, . .	London.
Christie, Andrew, . . .	Sydney.
Crofts, John Charles Thruston, .	Vancouver, B.C.
Dobson, Sydney Thornton, . .	London.
Dunn, Andrew Macfarlane, . .	Paisley.
Firth, Ambrose, ...	Sheffield.
Footner, Harry, ...	Crewe.
Garrard, George Mingay, . .	Broseley, Shropshire.
Garvie, James, ...	London.
Goodwin, Albert Beecham, . .	London.
Hancock, Samuel, ...	Singapore.
Harrap, George Thomas, . .	London.
Heath, Elijah Arthur, . . .	London.
Kay, George, ...	Nottingham.
Latta, James Gilmore, . . .	London.
McInnes, David Whitton, . .	London.
Mitton, Edward Moss, Jun., . .	Birmingham.
Molloy, Harry James, . . .	Tarikere, India.
Nasbey, George William, . .	Banbury.
Nicol, Robert Gordon, . . .	Aberdeen.
Platt, Francis James, . . .	Gloucester.
Platt, John, ...	Manchester.
Pope, Joseph Gordon, . . .	London.
Rider, John Hall, . . .	Plymouth.
Robinson, Joseph Drinkwater, R.N.R.,	Cork.
Robson, William Henry, . .	Birmingham.
Ross, William, Jun., . . .	Glasgow.
Scott, William George, . . .	Liverpool.
Simmance, John Frederick, . .	London.
Smeddle, John Henry, . . .	Darlington.
Stamer, Arthur Cowie, . . .	Darlington.
Stubbs, Joseph Hetherington, .	Manchester.
Taplin, John Minter, . . .	Ilford.

Turton, William Henry, . .	Woolwich.
Woodhead, William Richard, . .	Dudley.
Wootton, John, ...	Leicester.

ASSOCIATE MEMBERS.

Alder, George Frederick, . .	Tewkesbury.
Alexander, Joseph George, . .	Wolverhampton.
Baker, Henry Gouldthorpe, . .	Rotherham.
Ball, Edmund Bruce, . . .	Ipswich.
Barker, Thomas Perronet, . .	Birmingham.
Cheffins, Harold William Joshua, .	Swanscombe, Kent.
Cooper, George, ...	Leeds.
Cunliffe, Tom Arthur, . . .	Sunderland.
De Ville, Martin, . . .	Manchester.
Edwards, James George Benjamin, .	Leeds.
Enock, Eric Cuthbert, . . .	Dartmouth.
Everson, Frederick Charles, .	London.
Freeman, Walter William, . .	Stoke-on-Trent.
French, Arthur Houle, . . .	London.
Harwood, James Henry, . .	London.
Jackling, Daniel C., . . .	Mercur, Utah.
Kershaw, Grindrod, . . .	Rochdale.
Mansfield, James Francis, . .	London.
Martin, John, ...	London.
Middleton, Harry Herbert, . .	Calcutta.
Mills, Joseph Amos, . . .	Johannesburg.
Neal, Robert Henry Bennett, .	Plymouth.
Norton, Samuel Joseph, . .	Carnarvon.
Phillott, George Henry, . .	Cheltenham.
Powell, Ernest Brecon, . .	Weymouth.
Read, George Henry, . . .	London.
Russell, Hubert, ...	Holmfirth, Yorks.
Shiba, Chuzaburo, . . .	London.
Smith, Frederick Hugh, . .	London.
Spencer, Perceval, . . .	Thiant France.

STEINMETZ, ARTHUR SAMLER BERNARD,	Bedford.
STEPHENS, CHARLES ROBERT, . .	Falmouth.
STEVENS, EDWIN CHARLES, . .	London.
STOCKS, HARRY BENWELL, . .	Sheffield.
WESTON, GEORGE CAMBRIDGE, . .	London.
WILLIAMS, JOHN ELLACOTT, . .	London.
YEAMES, JAMES LAMB, . . .	Buenos Aires.
YOUNG, HENRY JOHN, . . .	London.
YOUNG, WILLIAM, ...	Sutton, Surrey.

ASSOCIATES.

DOUGLAS, LOUDON MCQUEEN, . .	London.
WATERLOW, DAVID SYDNEY, . .	Rickmansworth.

GRADUATES.

BLYTH, ERNEST BLACKSTONE, . .	Edinburgh.
BUTTERS, HOWARD, ...	Bradford, Yorks.
CRUICKSHANK, GEORGE SEYMOUR, .	Lincoln.
DEAN, GEORGE, ...	London.
DRAYTON, THEOPHILUS JAMES BRADLEY,	London.
EMBLETON, CHARLES ARNOLD, . .	London.
FLETCHER, GERARD MURRAY, . .	Liverpool.
GOODALL, FRANCIS HARRISON, . .	Nottingham.
HALE, HAROLD, ...	London.
HARRIS, FRANCIS GRAHAM REYNOLDS,	London.
HEMINGWAY, LEIGH, . . .	Wolverhampton.
HUTCHISON, PERCY, ...	London.
KIMBER, HARRY WATKINS, . .	London.
MANSFIELD, OLIVER, . . .	London.
NUTTER, HAROLD NORMAN, . .	Bradford, Yorks.
PEARSON, CHARLES DEARNE, . .	London.
PEREGRINE, WILLIAM HENRY, . .	Manchester.
POWELL, WILLIAM FOSTER, . .	York.
ROBERTS, ROBERT CORYTON, . .	Leeds.
SCHONTHEIL, THEODORE, . . .	London.

STEVENS, PERCY HERBERT, . . .	London.
STEWART, CHARLES, ...	Doncaster.
TRAFFORD, JOSEPH PETER, . . .	Tipton.
TREGONING, WYNN HAROLD, . . .	London.

The following Papers were then read and discussed :—

"The South Devon Atmospheric Railway, preceded by certain remarks on the Transmission of Energy by a partially rarefied Atmosphere;" by Sir FREDERICK BRAMWELL, Bart., D.C.L., LL.D., F.R.S., Past-President.

"The Launch of a Battleship;" by Mr. H. R. CHAMPNESS, Chief Constructor, H.M. Dockyard, Devonport.

"Railway Viaducts in Cornwall, Old and New;" by Mr. T. H. GIBBONS, Divisional Engineer, Great Western Railway, Plymouth.

At Half-past Twelve o'clock the Meeting was adjourned to the following morning.

The ADJOURNED MEETING was held in the Guildhall, Plymouth, on Wednesday, 26th July 1899, at Ten o'clock a.m.; Sir WILLIAM H. WHITE, K.C.B., LL.D., D.Sc., F.R.S., President, in the chair.

The following Papers were read and discussed :—

"The Mechanical Appliances employed in the construction of the Keyham Dockyard Extension Works;" by Mr. WHATELY ELIOT, Admiralty Superintending Civil Engineer, Keyham Extension Works.

"The Machinery of H.M.S. 'Proserpine' and H.M.S. 'Psyche,' as illustrative of the work done at Keyham, particularly with reference to the practical training of Engineer Students;" by Mr. ROBERT MAYSTON, R.N., Chief Engineer, H.M. Dockyard, Devonport.

"Outlet Valves at the Burrator Reservoir of the Plymouth Water Works;" by Mr. Edward Sandeman, *Member*, Borough Water Engineer.

"Refuse Disposal, and the results obtained from six months' working of the Refuse Destructor at Torquay;" by Mr. Henry A. Garrett, Borough Engineer and Surveyor.

The remaining Paper announced for reading and discussion was adjourned to a subsequent meeting.

The President proposed the following Votes of Thanks, which were seconded by Sir Frederick Bramwell, Bart., Past-President, and passed with applause:—

To the Worshipful the Mayor, Alderman John Pethick, and Corporation Land Committee of Plymouth, for their kindness in granting the use of the Guildhall for the present Meeting, and for the numerous facilities accorded in connection therewith; also to the Worshipful the Mayor of Devonport, William Hornbrook, Esq., for his hospitable reception of the Members at the Public Hall; and to the Chairman of the East Stonehouse Urban District Council, John E. Bone, Esq., J.P., for the united welcome they have accorded to the Members on their visit to the Three Towns.

To the Lords of the Admiralty; to the Admiral Superintendent of the Devonport Dockyard, Rear-Admiral Thomas S. Jackson; and to Rear-Admiral Henry J. Carr, late Admiral Superintendent; also to Major H. Pilkington, C.B., R.E.; and to the various dockyard officials for the efficient arrangements made by their kindness for the visit of the Members to their establishments.

To the Naval Commander-in-Chief, Admiral Sir Henry Fairfax, K.C.B., for permission to visit the schools on board H.M.S. "Cambridge" and H.M.S. "Defiance."

To the Right Hon. the Earl of Mount-Edgcumbe and to the Right Hon. the Earl of St. Germans for opening their Gardens and Grounds and Cotehele House to the Members.

To Sir John Jackson for the facilities and hospitality shown to the large number of Members and Ladies visiting the Keyham Extension Works; and to the Worshipful the Mayor of Plymouth, Alderman John Pethick, for his invitation to the Garden Party.

To the Municipal Authorities and Proprietors and Engineers of Works for inviting the Members to visit various places of interest; and especially to Messrs. Bywater and Co. for the loan of their steam launch, and the Devon Great Consols Mines Co. for lending their Count House for tea.

To the Directors of the Great Western Railway and of the London and South Western Railway for their kindness in providing special railway facilities for the Excursions; and to the whole of the Railway Companies for the special arrangements for members attending the Meeting.

To the Honorary Local Secretary, Mr. James Paton, for his advice and aid in maturing the arrangements.

The Meeting then terminated at a Quarter to One o'clock. The attendance was 217 Members and 53 Visitors.

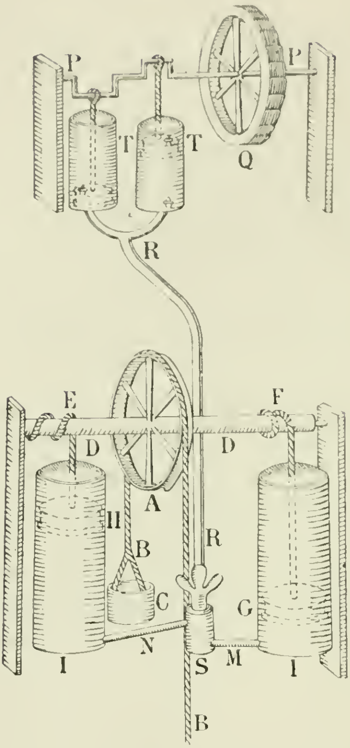
THE SOUTH DEVON ATMOSPHERIC RAILWAY, PRECEDED BY CERTAIN REMARKS ON THE TRANSMISSION OF ENERGY BY A PARTIALLY RAREFIED ATMOSPHERE.

By Sir FREDERICK BRAMWELL, Bart., D.C.L., LL.D., F.R.S.,
Past-President, of London.

Leaving out of consideration Savery's and such like machines for the raising of water by means of a partial vacuum produced by the condensation of steam—the first suggestion, so far as the writer is aware, for transmitting energy by the rarefaction of air, was made by Denis Papin, who, in 1695, published in Cassel a book called "Recueil de diverses piéces touchant quelques nouvelles machines," where, at page 36, is to be found the description of the drawing, Fig. 1, page 300.

Without repeating Papin's minute description, it will suffice to say that the waterwheel Q, by means of the double-throw crank-shaft P, worked two exhausting pumps T T, from which proceeded the common exhaust-main R to the place where the power was required to be developed. Here there were two open-topped working cylinders I I, containing pistons H G, on the under side of each of which a partially vacuous condition was, from time to time, to be made by connecting their respective pipes N and M alternately with the exhaust main R and with the atmosphere, by the operation of the central cock S. The pistons had ropes E and F attached to their upper sides; these ropes were wound in reverse directions around the axle D, which axle carried the large grooved wheel A, having over it the rope B, at each end of which were the buckets C, to raise the water.

FIG. 1. *Denis Papin*, 1695.

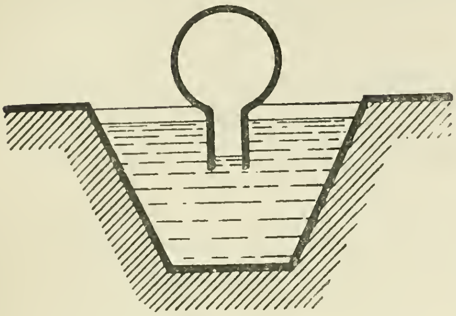


Papin says that such an apparatus, if he is not deceiving himself, will serve much more readily than any hitherto invented, to transport the force of rivers into places at considerable distances; to there draw water from mines, and to do other works which require much labour. At page 41 he says, one may find some means so that the machine itself will turn the cock S at the needed time; but he thinks it will be better to have a man to do this job, who will also be employed to empty the buckets as they come from the mouth of the mine.

It is extremely likely that, in the 115 years which elapsed between Papin's publication and the year 1810, there may have been propositions for the transmission of energy by air-pressure, but the writer has not come across them, and, so far as he knows, the matter lay in abeyance until that year (1810), when Mr. G. Medhurst proposed the propulsion of trains within a tube of 30 feet area, 6 feet high by 5 feet wide, by a pressure (not a rarefaction) of about 16 lbs. per square foot.

He says that this will be an adequate force to drive the air 50 miles an hour; but to propel the load he allows an addition of about 13¼ lbs., or something under 30 lbs. to the square foot, to move the air and the load of the train at 50 miles an hour. This he says can be done by a 180 H.P. engine.

FIG. 2. *Medhurst.*



Then he says: "In many cases it will be practicable upon the same principle to form a tube so as to leave a continual communication between the inside and the outside of it, without suffering any part of the impelling air to escape, and by this means to impel a carriage along upon an iron road in the open air with equal velocity, and in a great degree possessing the same advantages as in passing with-inside of the tube, with the additional satisfaction to passengers of being unconfined and in view of the country."

Then he proposed to employ a 12-inch tube.

It appears from a subsequent pamphlet that the mode by which he intended to make communication between the tube and the exterior was by a water seal, Fig. 2, but apparently he had discovered that the air-pressure of 3 lbs. and 6 oz. per square inch —that which he had assigned to a 12-inch tube—would be rather difficult to retain by a water seal, and he then proposed to use a 24-inch tube.

In this later pamphlet (1827) he suggested a rectangular iron tube, with a wrought-iron or copper "semi-top," as he called it, riveted to the flange and lifted by the projection of a wheel attached to the piston, and thus admitting the protrusion of an arm to connect the piston inside the tube with the external carriage. There is not any description of how the valve was to be closed and sealed.

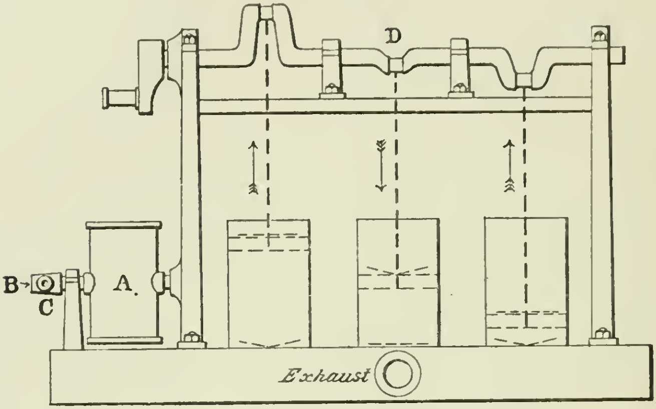
The writer has come across the name of Lewis as having done something with atmospheric transmission of energy in 1817, but he has not been able to trace the particulars of that which Lewis did.

In 1824, however, John Vallance took out his patent, No. 4905, so very well known to all who have interested themselves in this subject of transmission of energy by the pressure of the atmosphere.

Except that Vallance proposed to move his train by the rarefaction of the air, his scheme was a mere repetition of that of Medhurst already mentioned.

But the man who really developed this mode of transmission of energy was John Hague, to whom the writer was apprenticed.

FIG. 3. *Hague*, 1827.



Hague took out a patent, No. 5546, 1827, Figs. 3 and 4, wherein he proposed to have a proper number of exhausting pumps, working continuously and maintaining continuously a partial vacuum: a pipe was laid from the pumps to the place where the power was needed to be used, and he placed there an engine of the character of a steam engine, which engine was put to work by the pressure of the atmosphere upon the piston of the engine, on the other side of which piston there was the partially vacuous condition.

This system was very extensively followed.

In the year 1836, Hague took out a second patent, No. 7088, Fig. 5, for raising water by the use of a partially-vacuous condition. His plan was to have a succession of shallow cast-iron reservoir boxes placed, either in a shaft or on an incline, at vertical heights of about 20 feet apart, and to connect these boxes by rising water-mains, and also to connect them to an exhaust main. Say, for example, six boxes were to be used on the incline shown, and imagine

Fig. 4. *Hague*, 1827.

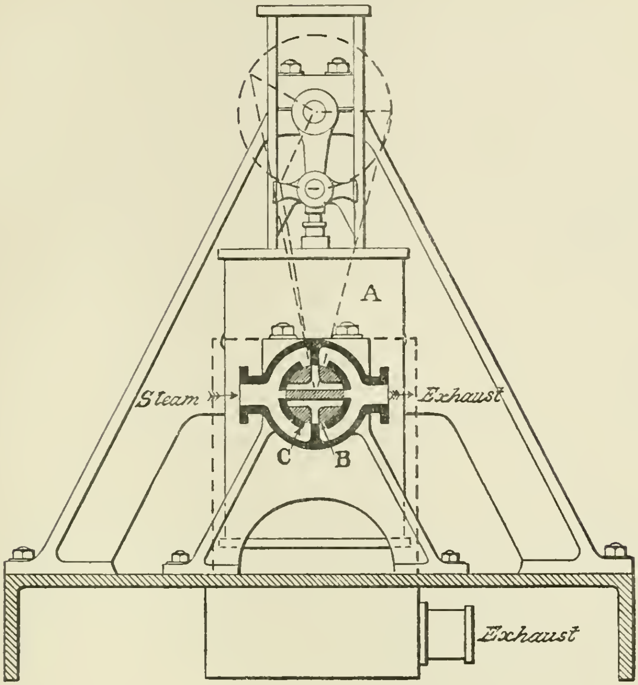
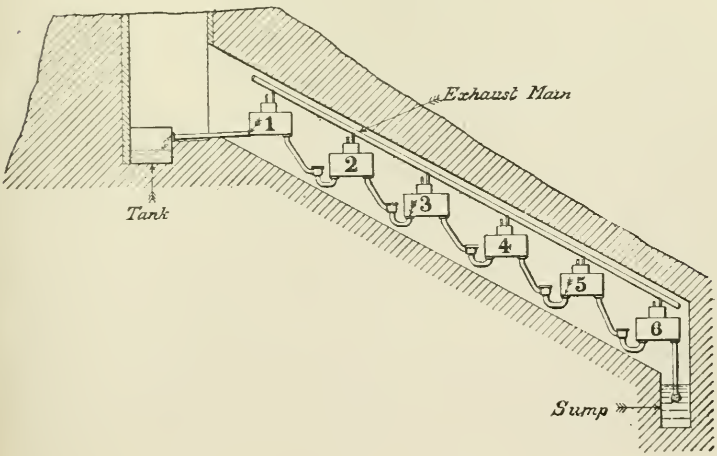


Fig. 5. *Hague*, 1836.

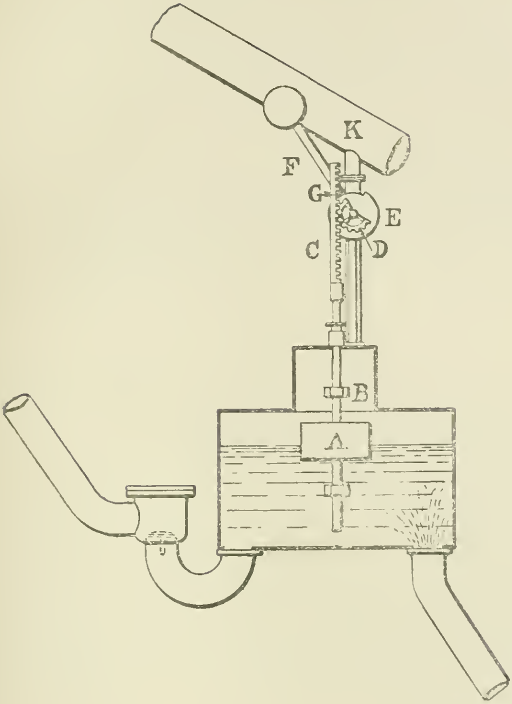


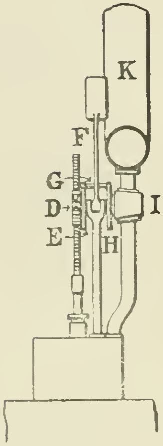
that Box 1, at the top, was delivering its water into a tank at the top of the incline; then Box 3, at the same time, would be delivering its water into Box 2; Box 5 would be delivering its water into Box 4, and Box 6 would be drawing its water from the sump. As soon as 1, 3 and 5 were empty, and 6, 4 and 2 were full, the connections of 2, 4 and 6 with the exhaust main were automatically closed, and connections were made for these boxes with the atmosphere; while, at the same time, and automatically, connections were made between Boxes 1, 3 and 5 with the exhaust main. These boxes at once began to fill from their immediately lower Boxes 2, 4, and 6, by reason of the water being forced up into them by the air-pressure. The merit of this invention was, that the boxes could be placed on an incline equally well as in a vertical shaft, and that they could be worked by a quiescent exhaust-main instead of by heavy moving rods, as in the case of pumps. The defect was that, while the vacuous condition must be such as to raise the water from the very bottom of an emptying box to the very top of a filling box, the mean effective lift was only the distance apart from centre to centre of the two boxes; thus there was a large amount of extra lifting, which produced no good result. Moreover, in practice (for these boxes were put to work), they failed to synchronize, and in this way the "pitch" in working was not kept up.

Figs. 6 and 7 show the method that was adopted to make the automatic reversals between the boxes and the vacuum main and between the boxes and the atmosphere.

As a box filled, its float A rose, and striking the stop B, raised the rod connected to the rack C, turning the pinion D, and with it the disc E, raised the loggerhead lever F, by means of the pin G, bearing against the edge of the notch in the disc E, until it assumed, just before the box was full, the vertical position. The last filling of the box took place very sharply in consequence of the rise of the float into the tubular top on the box, which top the float nearly fitted; thus the loggerhead F was thrown past the centre, and then its pin G ran away from the side of the notch which had been driving it, and the loggerhead fell; in falling, the other end of the pin G struck the notch-plate H, on the plug of a cock I, a blow, and rapidly

Fig. 6. *Hague*, 1836. Fig. 7.



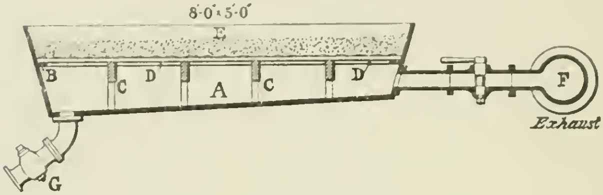


reversed it, cutting off the connection with the exhaust-main K, and making connection with the atmosphere. As the box emptied into the one above it, the reverse operation took place, so that when the box was empty the connection with the atmosphere was shut off, and that with the exhaust-main was re-made.

A previous use that Hague had made of a partially vacuous condition was one that can hardly be called, in the usual sense of the term, "transmission of energy," but it was very ingenious, and its insertion here may perhaps be permitted. In the year 1816 he took out a patent, No. 4048, for purifying sugar by means of partial exhaustion. The readers of this Paper are begged not to confound this with Howard's Vacuum Pan, which was a contrivance for boiling

off, by the aid of steam-heat, the needed amount of water from the sugar solution, but doing it at a low temperature by reason of the highly vacuous condition in which the ebullition was effected. Hague employed no heat in his process at all.

FIG. 8. *Hague*, 1816.

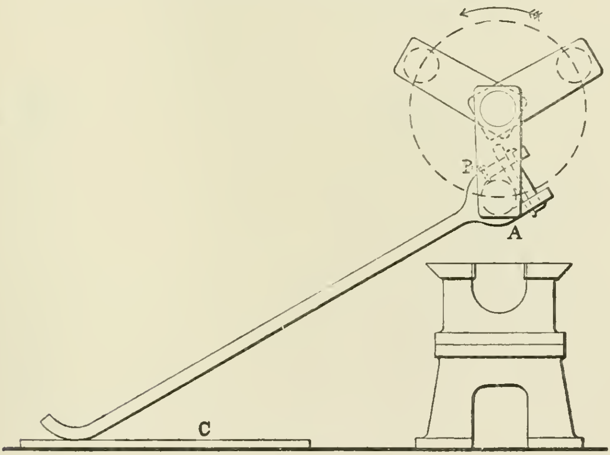


He used a cast-iron pan, such as A, Fig. 8, having a small internal flange B about half-way up, which flange, with the aid of a wooden framework C, supported a frame D, which carried a perforated copper surface surmounted by a hair cloth. On this cloth, the coarse sugar E, was filled in, extending quite up to the sides of the pan three or more inches deep, care being taken to lay it uniformly, so as to leave no particular air-channels; and then, on opening connection with the vacuum main F, a partially vacuous condition was produced below the hair cloth, and the pressure of the air drove the colouring matter, which had been adhering to the crystals, through into the lower part of the pan. This operation was facilitated by sprinkling the sugar either with water or with a white sugar solution. When the crystals had been cleaned, the communication with the exhaust main was shut off; air was admitted, and the molasses which had collected in the bottom of the pan was drawn off by the cock G.

Large numbers of these exhausting apparatus and pans were made. The ordinary form of the engine and pumps used for these apparatus was that shown in Figs. 3 and 4. A high-pressure oscillating cylinder A made its inlet and exhaust by means of a cone B on the cylinder working in a shell C. The writer does not put this forward as an economical engine; but he adduces it as a simple one. The engine worked a 3-throw crank-shaft D, Fig. 3,

made in cast iron. The strokes given by this crank-shaft were not uniform within one-eighth, or it might be within one-quarter of an inch, for the mode of turning the pins of the throws was simple, but not exact. The 3-throw shaft, Fig. 9, was "chucked" in the lathe upon its centres. Then an implement A, somewhat like a connecting-rod, was put round the throw of which the pin was to be turned. This connecting-rod, so far from being furnished with a brass, was furnished with a cutter B. The prolonged tail of the connecting-rod slid backwards and forwards on a boiler-plate C, laid on the floor. The cutter B was screwed up as needed, with the result that practically round crank-pins were obtained without the necessity of "re-chucking" the shaft upon each one of the crank-pins. This mode of turning was called by the men "Fox-chasing."

Fig. 9. *Three-Throw Crank-shaft. "Fox-chasing."*



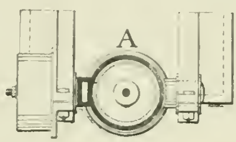
There were foot-valves in the bottoms of the pumps, and corresponding valves in the buckets, but no head valves, the pumps being open-topped. These engines, as has been said, were very simple; they could be worked by the most ignorant "black" on a sugar estate, and, except on the score of fuel economy, they did their work very well.

When the partial exhaustion was employed—neither for purifying sugar, nor for the direct raising of water, but for driving a motor—that motor was a repetition of the oscillating steam engine, Fig. 11. There was, in the very early days of distribution of energy, a large field open for this particular mode. Hague made a very pretty model of an ordinary wharf crane, and showed it working and raising weights, while the exhaust pump was in another room, the connection being made by a pipe.

Figs. 10 to 14 are taken from the crane drawing attached to the specification of Hague's patent, No. 5546, 1827. Fig. 10 is a

Oscillating Cylinder. Hague, 1827.

FIG. 10.



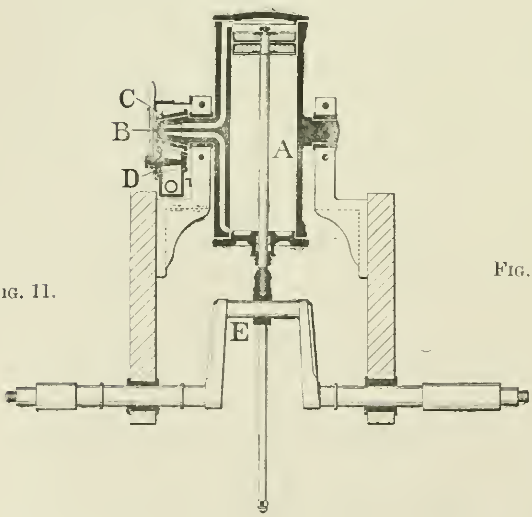


FIG. 11.

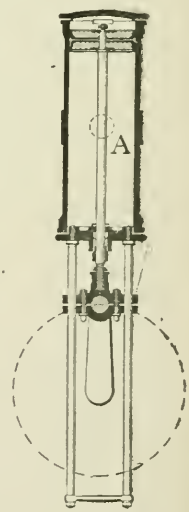


FIG. 12.

sectional plan. Fig. 11 shows a section of the oscillating cylinder A, with its cone B, working in the shell C, having beneath it the reversing cock D. The great length of the crank-pin E, was to admit the usual endway motion of the shaft to vary the speeds of the gear. Fig. 12 is a transverse section. Fig. 13 is a section through the cone B, shell C, and reversing cock D. Fig. 14 is an external elevation of these parts. The model and the explanation of how the crane would thus be worked from a central steam-engine impressed the directors of the St. Katharine's Docks very much, and they were quite disposed to accede to Hague's proposition to do the work of these docks by means of the pneumatic cranes, instead of by the

Oscillating Cylinder, Hague, 1827.

FIG. 13.

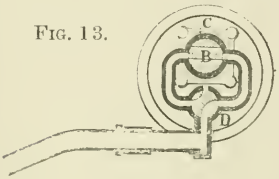
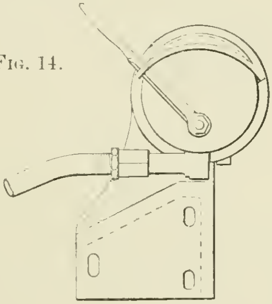


FIG. 14.



tread-wheels, then in use at the adjoining London Docks. But Hague, whose ingenuity was undoubted, never kept his promise as regards time, and the result was that this chance of working the cranes of a dock from a central steam-engine driving exhausting pumps was lost to him.

Such cranes were put to work later on at Whitstable, and continued to be employed there for very many years; indeed until 1886.

A few similar cranes were erected at London Bridge Station.

At one time (date forgotten) the Admiralty were prepared to make an experiment in driving the various machine-tools at Woolwich Dockyard by means of partial exhaust engines applied to each tool, thus dispensing with line shafting.

The writer refers to Fig. 15, which is a reduction of the original sketch, made by him for the guidance of the draughtsman, in preparing the drawing for certain of these dockyard engines.

FIG. 15. *Partial Exhaust Engine.*

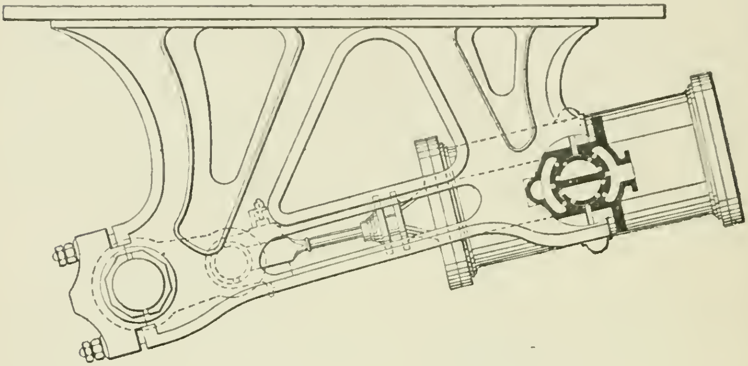
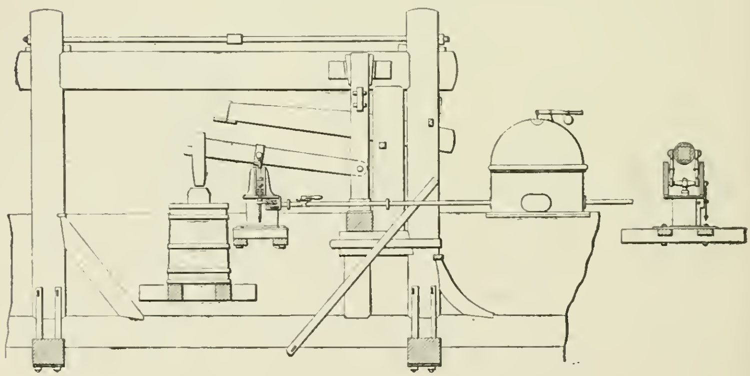


FIG. 16. *Pneumatic Tilt Hammer. Hague,* 1827.



In this same patent of 1827, Hague showed the partially vacuous condition applied to a tilt hammer, Fig. 16. The writer, when an apprentice, saw a small tilt of this kind, intended for planishing the bottoms of frying pans and such like matters, put to work, with

the result that the hammer disappeared. The reciprocations were many hundreds a minute, and thus the outline of the hammer was entirely lost, and nothing but a mere " blur " resulted.

Hague applied this mode of transmitting energy to driving the machinery of powder mills, so as to remove the danger of steam-engine fire to any distance needed for safety. He also applied it to work the individual cutting-out presses and coining presses of a mint which he constructed for Rio Janeiro.

When working the motors by the pressure of the air seeking entrance into the partially vacuous cylinder, it was found that long before the freezing point was reached in the ordinary atmosphere, icicles would form about the nozzles of these motors. This was a source of considerable astonishment. It was also found that in the top of the air-pumps already mentioned, the air came out of the piston-valves very sensibly warmed. In those days, this warming was attributed to friction; but, owing to the pumps being open-topped, there was so great a circulation of atmospheric air that the temperature never rose to any inconvenient point. When, however, air-pumps were applied to the beams of steam engines, and were made double-acting, then the increase of temperature made itself inconveniently felt, and the writer devised a means of reducing this, by introducing a small injection of cold water at the two ends of a double-acting air-pump.

It did not occur to anyone to take indicator diagrams from the pumps, either with or without the injection; but it was found that, with the injection, the steam-engine driving the pump would make about 10 per cent. more revolutions when the injection was on than when it was shut off, the vacuum being equal.

The writer has thought that the foregoing might be interesting, as leading up to the subject of Atmospheric Railways, and also as setting forth the work of a man, John Hague, in the way of conveying energy by the rarefaction of air, who was the master to whom Jacob Samuda, who did so much to endeavour to develop Atmospheric Railways, had been apprenticed, and who, under Hague, had been thoroughly imbued with the system of transmission of energy by partial exhaustion.

Some years later, 1846 to 1850, the writer conceived the idea that Vallance's system would be peculiarly applicable for Subterranean Railways in London, which railways he proposed to carry down well into the London clay, and thus to obtain a good stratum in which to work, and also a position below and clear of all the sewers and other matters situated a short distance beneath the surface. He proposed to make a rectangular tunnel, Fig. 17, large enough to contain a first-class railway-carriage body, the wheels being at the ends of the carriage, the body hanging down below the axles, and to make this rectangular tunnel entirely of cast-iron plates. The railway was originally designed by him to extend from Charing Cross to the Bank, but subsequently it was proposed to carry it to Hyde Park Corner. At the City end, its station was to be in certain property (poor property in those days) at the back of the Old Jewry; and the writer, in conjunction with his late fellow-apprentice, Mr. Homersham, and an architect, Mr. Boulnois, worked out the system, including the method of taking passengers up and down by means of hydraulic lifts, Fig. 18. The writer sufficiently impressed a firm of solicitors with the merits of the idea, as to cause them (he believes in 1846) to prepare the requisite parliamentary notices for making a sample railway of this kind over the then Hungerford Suspension Bridge, Figs. 19 to 21, page 314, so as to carry passengers backwards and forwards between the South Western "Waterloo" Station and a station to be made in Hungerford Market, but the matter went no farther.

FIG. 17. *Proposed Hyde Park and Bank Subterranean Railway.*

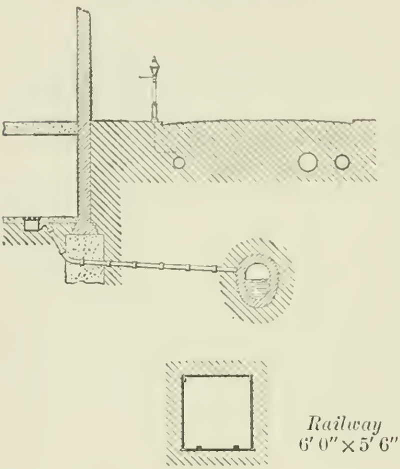


FIG. 18. *Proposed Hyde Park and Bank Subterranean Railway. Intermediate Station.*

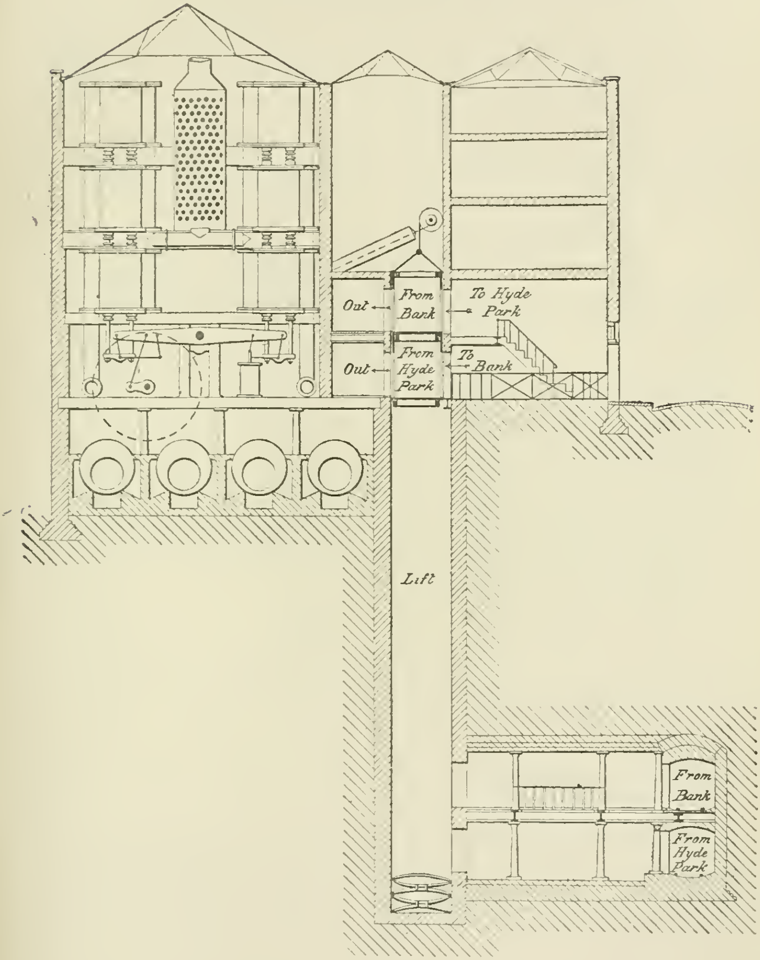


FIG. 19. *Hungerford to Waterloo*, 1846.

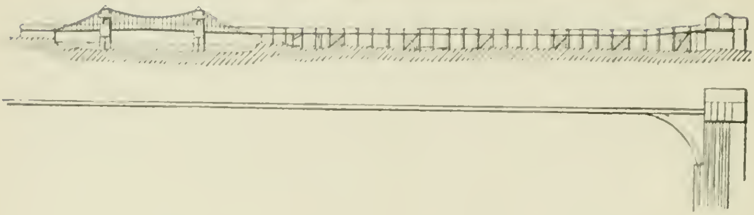
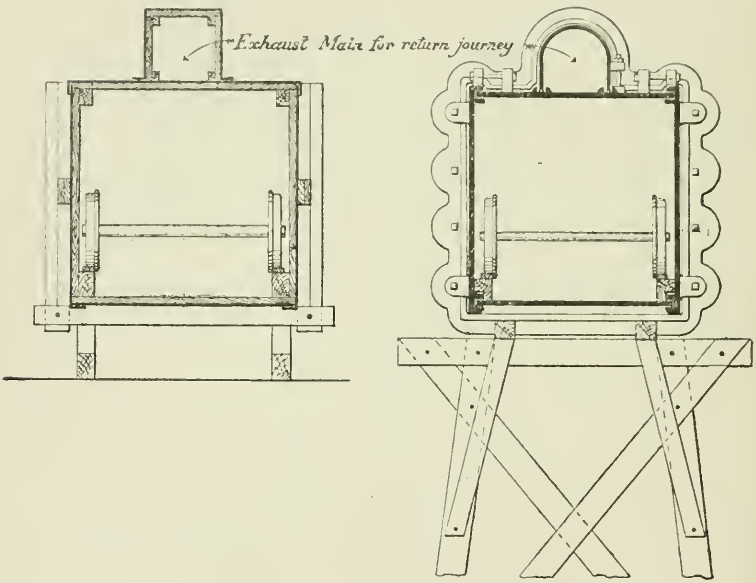


FIG. 20. *Section of Wood and Sheet-iron Tube over bridge.*

FIG. 21. *Section of Cast-iron Tube between the bridge and station.*



Vallance's (Medhurst's) system of Atmospheric Railway was really put to work in 1861, in the case of the "Pneumatic Postal Despatch," which was, in that year, laid down experimentally in Battersea Fields. A ⌓-shaped tube, 2 feet 9 inches high by 2 feet 6 inches wide, was employed. The tube contained a piston, to which were attached a number of trucks forming the train, to be filled with postal bags. In 1863 a line on this system was laid and got to work from Euston

to the Holborn Post Office, a distance of about one mile and a half, with the intention of going forward another mile to the General Post Office. In this case the ⌂-shaped tube was as much as 4 feet high by 5 feet wide. The trains were "blown" and "sucked" backwards and forwards. A vacuous or a pressure condition of a few inches of water was found sufficient for the propulsion. It cannot be said that this was not a passenger railway, for several gentlemen, including Mr. Clarke Hawkshaw, had the hardihood to treat themselves as parcels and to make the journey. This system was used for some time as far as Holborn, but, owing to station difficulties at St. Martin's-le-Grand, it was never put into operation there. All working was ultimately given up, and the machinery was removed. The tube itself is still *in sitû.*

In the year 1839, Samuel Clegg patented (No. 7,920) the Atmospheric Railway System, as commonly understood and put in practice, and, in the year 1840, an experimental length was laid down at Wormwood Scrubs.

In 1842, the report of Messrs. Smith and Barlow led to the system being tried on the Kingstown and Dalkey line; in 1843 Mr. (Sir) William Cubitt, determined to use it on the Croydon line; and, on the 19th August 1844, Mr. Brunel wrote to the directors of the South Devon line, recommending the adoption of the atmospheric system.

The South Devon Railway, it need hardly be said, extends from Exeter to Plymouth, along the right bank of the River Exe, until the seashore is reached, then along that shore to Teignmouth, up the left bank of the Teign to Newton Abbot, and from there to Totnes and Plymouth. There were pumping-engines at Exeter, Countess Weir, Turf, Star Cross, Dawlish, Teignmouth, Summer House, and Newton: eight engines in about 20 miles, so that the average distances between the engine-houses would be a little under 3 miles. The section, Fig. 22, page 316, shows that, while from Exeter to Newton the line was fairly level, there occurred on each side of the Dainton Tunnel heavy inclines of a mile and a half, or two miles in length, and having gradients ranging from 1 in 40 to 1 in 97. It will also be seen that, on going out of

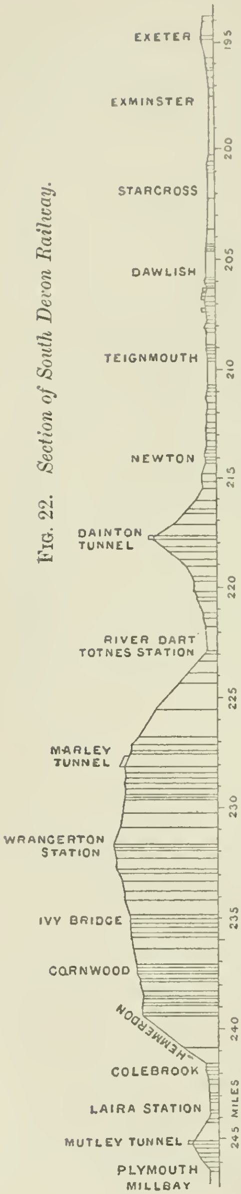


FIG. 22. *Section of South Devon Railway.*

Totnes, there is a very heavy gradient, part of it as much as 1 in 51; and again, a steep gradient at Hemmerdon of as much as 1 in 42, and less gradients at the Mutley Tunnel, near Plymouth. Brunel's great temptation to use the atmospheric system was that by getting rid of the weight of the locomotive, and by employing larger atmospheric tubes on the gradients, he hoped to be able to deal with inclines of this kind, and thus make a cheaper line. Moreover, he persuaded himself and a Select Committee, which sat in March and April 1845, to believe that a single line on the atmospheric system would do as much train-work as a double line on the locomotive plan, and the comparative estimates of cost were based on this view of the greater output of work by the atmospheric line. The atmospheric system was actually laid down nearly the whole way from Exeter to Newton. This was accomplished by 1846, but great difficulties were experienced with the pumping engines and machinery, a detail in which no trouble had been apprehended. It is not clear what was the nature of the difficulties. The engines had been provided by Messrs. Boulton and Watt, Messrs. Maudslay, and Messrs. Rennie; but on the 27th August 1847 Brunel reported to the South Devon shareholders that the line was being worked by locomotives, while the atmospheric was being got into order. On the 1st September 1847 it was resolved not to extend at present the atmospheric system beyond Totnes. On the 8th September it was reported that four atmospheric trains ran each way daily. In

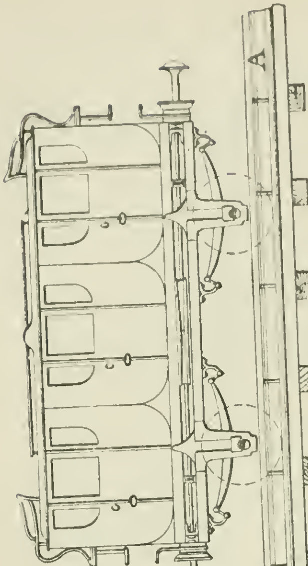
the life of Brunel, it is stated that 865 horse-power were actually required to do the work, that he had a right to expect would have been done by 300 horse-power. By August 1848 the valve had begun to fail throughout its length. The cost had been £1,160 per mile, and on the 19th August 1848, just four years to a day after Brunel had advised the trial of the atmospheric, he reported that he did not recommend its extension, and, in fact, suggested it only as an assistant, on inclines. The directors then suspended operations, and, after the 9th September 1848, locomotives were used throughout.

The system, as is probably well known to all present, consisted (Figs. 23 to 26, page 318) in laying a continuous cast-iron tube A, on the sleepers between the rails, which tube had a valve-covered slit the whole way along the top.

The piston B, Fig. 23, was placed in the tube, and an arm C, from an attachment to the rear of the piston, came out through the slit and under the valve G, Fig. 26, and was then attached to the leading carriage of the train—a species of brake-van, which also carried passengers. The valve G, that covered the slit, was in the form of a continuous belt secured at one edge to the cast-iron tube, but capable of being lifted at the other edge. This belt was strengthened by wrought-iron plates above and below, Fig. 25. Assuming the valve to be closed, and to be air-tight, and the exhausting pumps to be at work, there would be produced a greater or less vacuous condition along the whole length of the pipe, and the belt-valve being lifted by rollers H, Fig. 23, at the rear of the piston, an opening was thus provided which allowed the connecting arm C to pass, and also allowed the atmospheric pressure to be readily exercised upon the piston area, giving (according to the amount of exhaustion) a pressure of about 8 to 10 lbs. per square inch.

It would appear, from the evidence taken before the Parliamentary Committee in 1845, that as many as three sizes of tube were proposed for conjoint use on the South Devon Railway—13-inch, 15-inch, and 22-inch—and that Brunel was designing an expanding piston, so as to be capable of going from one size tube to other sizes ; but it would seem that, upon the comparatively easy portion

South Devon Railway.



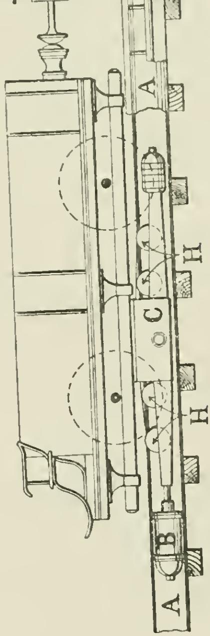


FIG. 23. Leading Carriage.

Tube, Valve, etc.

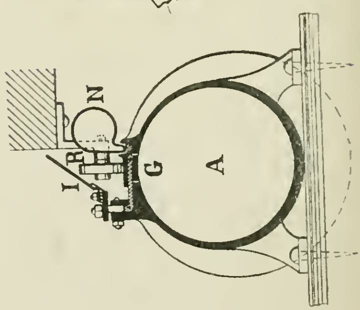


FIG. 24.

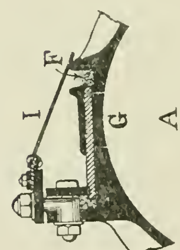


FIG. 25.

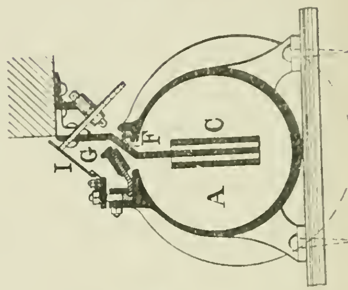


FIG. 26.

FIG. 27.

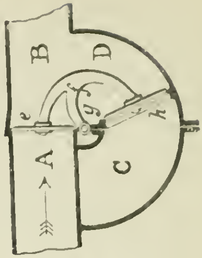


FIG. 28.

of the line which was actually laid, a tube of only 13 inches was employed. Taking the 13-inch piston there would be given at 10 lbs. effective a pull of some 12 cwt. The travelling was most luxurious. No noise, no smoke, no cinders, no smell.

It is easy to see how, as the rollers H, Fig. 23, attached to the piston went along, they would raise the valve, so as to allow of the passage of the arm from the inside to the outside of the tubes; but it is not so easy to see how the valve, which had been readily raised, could be as readily and securely bedded air-tight again.

The shutting of the valve was done by means of a roller R, Fig. 24, pressing it downwards into a seating of beeswax and tallow, F, Fig. 25, which it was sought to make sufficiently soft by a charcoal fire heater N, about 5 feet long, supported and running along with the carriage which had pressed the valve down. Above the valve there was a cover I, Fig. 25, formed of thin iron plates, hinged with leather, to protect the valve from snow and rain.

Sometimes the valve closed sufficiently air-tight, sometimes it did not; and when it did not, the engine pumped on in vain, while the train had to wait, helpless, at the station.

All sorts of valve schemes were proposed, and as many as seventeen patents dealing with the matter were taken out during the years 1844 and 1845.

It has already been said (page 315), the line was separated into sections of about 3 miles, each having its own exhausting engines.

To enable the train to pass from one section to another, valves, as shown in Figs. 27 and 28, were employed. Shortly before leaving the section along which the train had been travelling, the piston passed over the inlet to the exhaust-pump, went on by its momentum, compressed the remaining air in front of it, until it opened the valve, shown at Fig. 27, against the atmosphere.

The train then travelled, as shown by the arrow, into the end A, at Fig. 28, where it found in front of it a valve *e*, carried by a frame *f*, hinged at *g*. The lower end of *f* carried a piston valve *h*, of somewhat greater area than *e*. The line tube to the right hand B, was exhausted in readiness for the train, the superior area of *h* keeping the valve *e* closed, there being a connection between C and

the atmosphere. On the approach of the piston, the train moved a slide valve, so as to cut off the atmosphere from C, and to put C into connection with the vacuous condition. Thereupon, the pressure being taken off the valve *h*, the valve *e* yielded to the weight of the atmosphere and fell down, clear out of the way of the piston.

After working on the Croydon line from 1845 for a comparatively short time, the system had to be abandoned.

After working on the South Devon line (for a portion of it only) from some time in the year 1846 to some time in the year 1848, the system there, as has already been said, was abandoned.

After both the Croydon and the South Devon lines were given up, the atmospheric system worked for very many years (until 1855), between Kingstown and Dalkey, and up to even a later date in France, at St. Germain.

It is believed that there is not now any line on this system in existence.

Although the Electric Telegraph had been contemplated for the South Devon line, as being a most important adjunct for working a railway on the atmospheric system, it was not ready until the determination to abandon the system was being considered.

It can easily be understood with the line in sections, each section having to be exhausted in advance of the approach of the train, that if there were no telegraph, the only safe method of working would be to exhaust the section according to a time-table, and to keep it exhausted until the train really arrived.

Now, it appears it was contemplated that three minutes would suffice to exhaust a section, but it commonly took five, the difference being presumably due to leakage; and thus, if a train were ten minutes late, this leakage went on for fifteen minutes instead of five, involving ten minutes' extra expenditure of engine power.

It seems incredible to suppose that the valve could be made quite tight along its whole length. When it is considered that in a three-mile section there are 190,080 inches, so that $\frac{1}{1000}$th of an inch opening, continued for the whole length, would give an area of 190 inches, equal to rather more than a 15-inch pipe, the difficulty of obtaining absolute air-tightness appears very great indeed.

It thus became most important, for the economical working of the system, that the exhausting engine should be started as and when needed, having regard to the actual arrival of the train, as signified by telegraph, and not in mere obedience to a time-table.

When to the leakage loss there is added that due to the heating of the air (even after allowing for the reduction which may be made by injection into the pumps, or by jacketing them with cold water), the percentage utilised of the power expended is probably very low.

It will be remembered that, in Brunel's life, it has been stated that he found 865 horse-power exerted only yielded 300 horse-power, not quite 35 per cent. effective.

To set against this, there are, no doubt, important savings arising from replacing the great weight of the locomotive and tender by the comparatively trifling weight of the piston and leading brake-carriage: the ability to use lighter rails, owing to the absence of the locomotive: and the greater length of time for which these rails would last.

The writer was almost a daily traveller, for many years, upon the Blackwall Railway, when worked by ropes, and he distinctly remembers the practical immunity of the original iron rails of the Blackwall line from wear, as long as locomotives were not used.

Although the result has been failure, and although, in these days of electric possibilities, it is not likely anyone will revive the South Devon Atmospheric System, nevertheless, the writer thinks Mechanical Engineers will agree that a grateful recollection of the practical trial should be cherished, and that their thanks (tardy as they are after half a century) are due, with interest for the delay, to Isambard Brunel and to the Directors of the South Devon Railway, for having (wisely, as the writer thinks, notwithstanding the result) essayed, on a large and working scale, such a promising and delightful system of railway journeying as Clegg and Samuda's Atmospheric Railway.

Discussion.

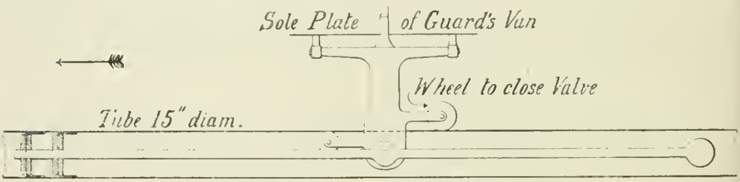
The PRESIDENT moved a vote of thanks to the author, which he said would be included in the Proceedings of the Institution.

The motion was carried by acclamation.

Mr. VAUGHAN PENDRED said that in 1852 and 1853 he was living at Dalkey and during that time took a great deal of interest as a lad in the Atmospheric Railway, and used to travel sometimes twice a week on it. The principal difference between the arrangement shown on Figs. 23 to 26, page 318, and the Dalkey line was that there was no metal covering-plate whatever to the slot in the 15-inch pipe, Fig. 29, and there was no wax used to keep the joints tight. The

Kingstown to Dalkey Atmospheric Railway.

Fig. 29. *Diagrammatic sketch of Piston-carriage, etc.*



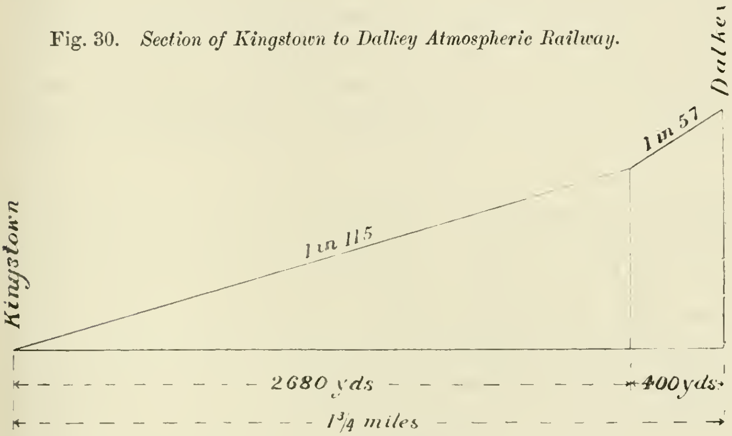
longitudinal valve was a continuous leather strap with iron plates about 8 inches long, riveted inside and outside. It would be understood that from the system of working by exhaustion considerable condensation took place, water vapour suspended in the air being deposited, according to a well-known thermo-dynamic law, as the pressure fell. The result was that the double piston, the leather, and everything connected with it, were always wet, and the wet leather was found to make a joint sufficiently tight. At all events he had never known an instance in which the line did not work because of the failure of the joint. A man who worked upon this Atmospheric Railway informed Mr. Cronin, his present

superintendent, that the leathers in the pistons were made of best butt leather, and usually lasted from six to eight months.

The PRESIDENT asked what was the length of the line.

Mr. PENDRED said it was $1\frac{3}{4}$ miles, Fig. 30, and the gradient was about 1 in 103. The trains were hauled up by the atmospheric action, and they ran down by gravity. The trains ran every half hour. The pumping engine at the Dalkey end was a vertical engine, with a vertical pump and a fly-wheel in the centre between the two. Steam

Fig. 30. *Section of Kingstown to Dalkey Atmospheric Railway.*



was supplied by two Cornish boilers, and the engines were started five minutes before the half hour began. There was no telegraph at that time, nor any communication whatever by signal between Dalkey and Kingstown. Three men were employed in the engine house, one of whom was the fireman, another the chief engineer, and the other was a species of greaser or attendant who, after the engine had been started for five minutes, went to a window from which he could see when the train was coming up the incline, and told the engineer to stop the engine. The running time on the line was about three or three and a half minutes to five minutes. He had travelled at eighty miles an hour on this atmospheric line. The front van was not

(Mr. Pendred.)
arranged as shown in Fig. 23, page 318; it was a regular guard's van, which also carried third-class passengers. There were two carriages, a composite carriage and the brake-van in front. The gauge was 4 ft. $8\frac{1}{2}$ ins., not 5 ft. 3 ins., which was now the Irish gauge, and the trains ran in connection with the Dublin and Kingstown trains. What was then the atmospheric railway had now become part of the Dublin, Wicklow, and Wexford system. The gradients had been flattened and there was no relic at all left of the old plant. One of the Cornish boilers was generally used to supply the steam, but sometimes both were used. The second one was generally understood to be a stand-by. They were worked on the slow-combustion system. The whole time during which the pump was at work was at the maximum ten minutes in each half hour; during the rest of the time the boiler was simply bottling up steam for use. The pressure was about 45 lbs. The engines were parallel motion engines and not slide guides. As well as he could remember, the stroke was about five feet, and the diameter of the pumping cylinder about three feet. It was possible that he might have some notes of that, but he could not give any precise data at the moment. On Sundays three coaches were put on and sometimes four, and then there was considerable difficulty in getting the trains to enter Dalkey terminus. Sometimes they did not go fast enough to run up the hill, because the pipe left off one hundred yards or so from the station. He had seen all the passengers turned out on the side of the embankment and compelled to push the train up before they could go any further. That was a species of Sunday work. The great feature about the line he thought was that it never broke down; it always worked. People were always sure of getting as far as the pipe went. He had never heard of an instance of the piston sticking and the train having to run back, and had never heard of an instance when the piston did not get out of the tube. When the train came up to Dalkey station, the guard put a lever on to the square end of the vertical bar passing through the floor of the carriage, Fig. 29, page 322, and swung the whole of the piston-carriage on to one side, where the bar was hooked. The train then ran back to Kingstown by gravity, the piston, &c., being outside the tube. The

train overran the tube a short distance, the piston-carriage was dropped, and the train allowed to run forward until the piston again entered the tube. The vacuum was measured by a mercury barometer, and he thought the average used to be on the Kingstown end about 8 lbs. or 16 inches. He might mention that at all times the valve leaked, although not much, but enough to make a sensible hissing noise, and if one were standing at the side of the line, one could always tell when the engine was started by hearing in the distance on a calm day a little hiss which came running all along the line, showing the gradual process of exhaustion in the pipe. Some people used to imagine that, as soon as the pumping began at the Dalkey end, a vacuum was obtained at the other end, but that was not the fact. It took about five minutes to exhaust the pipe sufficiently to start the train. He did not think there was anything more he need mention, but if there was any question any member might wish to ask he should be glad to answer it if possible.

The PRESIDENT asked if the line was fairly straight.

Mr. PENDRED said it was not; there were many sharp turnings.

The PRESIDENT also asked how long the line continued to work.

Mr. PENDRED thought it was mentioned in Sir Frederick Bramwell's Paper from about 1842 to 1855.

Mr. ARTHUR NORTON asked what was the method employed in braking the train.

Mr. PENDRED said there were ordinary screw brakes in the guard's van. He might mention that when the train came up very fast indeed with a light load, which was sometimes the case, the brake was applied long before the piston got out of the tube, but on one or two occasions the whole train ran through the station and right through the gates. He could not call to mind a case in which anybody was ever killed or seriously injured.

Mr. Henry Lea, Member of Council, asked whether the pipes were bored, and if not, what other arrangements were made for the piston to travel.

Sir Frederick Bramwell did not think they were bored. The piston travelled by having an extremely flexible coupling.

Mr. Henry Davey, Member of Council, said it was an interesting fact in connection with the historical part of the Paper, that in 1830 Boulton and Watt at their Soho works drove several of their large machines from a central pumping engine by the system of distribution of energy described in the Paper. The fact was recorded in Smile's Life of Nasmyth. Nasmyth, on visiting Boulton and Watt's works in 1830, found the system, which was designed by Murdock, in operation.

Mr. Bryan Donkin, Member of Council, asked if Mr. Pendred would kindly procure for the Institution a section of the line at Dublin he had been good enough to describe. He supposed it was possible to have a profile.

Mr. Pendred said he did not know whether a profile could be found now.* It was possible there might be one in existence, but he doubted it. The line had been considerably flattened since, and at the present time it was entirely different in gauge and gradients.

Sir Frederick Bramwell, Bart., Past-President, thought he should mention that Clegg and Samuda's patent would not be found under "Railways" but under "Valves." He supposed the fact was that they found that Medhurst, not in the plan he proposed for the water seal, but in the other plan of having a tube with a partially hinged top, had entirely anticipated them in the way of making

* Fig. 30, page 323, has been kindly supplied by Mr. R. Cronin, Locomotive, Carriage, and Wagon Superintendent of the Dublin, Wicklow, and Wexford Railway.

communications between an internal piston and an external carriage. Medhurst did not disclose any mode of making that tube airtight when the valve was put down again, or how to put it down, and it would be found that the patent of Samuda confined itself to the mode of sealing the valve. With respect to the Medhurst patent, he wished to call attention to the fact that so long ago as 1810 Medhurst pointed out that, with a carriage running on iron rails each side of the tube, a speed of fifty miles an hour might be attained. Brunel persuaded himself, and a Committee of the House, that with a single atmospheric line as much work could be done as with a double line on the ordinary plan. He had no doubt that Brunel honestly believed it, but he, Sir Frederick, had never been able to follow it. He thought the directors were wise in adopting the system. They took the best advice of the day, and the system was already working to more than an experimental extent, and if it had answered, the result would have been a great deal better as compared with locomotive traction. The charm of travelling was not to be described. However, it did not answer, but he thought the men who agreed to use it must be judged by what they had before them at the time, and not by the result.

The President said that Mr. H. M. Brunel was unfortunately unable to be present, but he was sure Sir Frederick Bramwell would be glad if Mr. Brunel would add any contribution to the discussion in writing, Sir Frederick of course having the right to comment upon that contribution.

Mr. H. M. Brunel wrote, referring to the chapter on "The Atmospheric System" contained in the "Life of I. K. Brunel," published in 1870, and added that he had no further remarks to offer on the atmospheric railway question.

THE LAUNCH OF A BATTLESHIP.

By Mr. H. R. CHAMPNESS,
Chief Constructor, H.M. Dockyard, Devonport.

Introductory.—The author offers some remarks on this subject partly upon the suggestion of the President, and also because the members of the Institution will naturally be interested in what was a considerable feat in engineering, and, at the same time, a striking development of the resources of the port in which the Summer Meeting is being held.

The launch was that of Devonport's first modern battleship, H.M.S. "Ocean," Plate 85, the first since the days of wood shipbuilding, the preceding ship having also been named "Ocean," and launched as long ago as 1863. How great the advance was will be understood from the fact that the weight of the present ship as launched was 7,110 tons, the nearest approach to this being a steel cruiser, whose launching displacement was 2,830 tons, sent off the same slip in November 1890.

When it is remembered that a very few years since, the opinion was seriously expressed that battleships could not be built at Devonport, while, during the last twelve months, three such ships have been upon the blocks, two of which are now afloat, the third well advanced for launching, and a fourth soon to be laid down, it will be admitted that the development promises to be permanent.

It is true that this is not a record weight even for battleships launched from the Imperial Dockyards, and it has been far eclipsed by what was lately done in launching the s.s. "Oceanic," when 11,000 tons slid into the water, though the mean pressure per square foot of the cradle was only 2·35 tons as compared with the 2·5 tons of the

"Ocean"; but those most closely responsible for ship launching have little desire to create records of this sort, and certainly so far as the chief constructors of the Naval Dockyards are concerned, the builders of the "Oceanic" are welcome to their pre-eminence.

Building Slips.—An incidental evidence of the growth in dimensions of modern ships is seen in some of the naval yards, where the building slip has been adapted for launching the present ships of great beam and flat floor, by cutting away the sides of the slip at the lower end to enable the full section of the ship to clear it. This was avoided at Devonport by increasing the width of the slip throughout sufficiently to provide for all probable increases of beam; the slip was also lengthened at the upper end, and two concrete piers 25 feet wide were built at the lower end in wake of the launching ways, to carry the ship into deep water when the fore end of the cradle left the groundways.

How well these old slips were piled is clear, since, in spite of the enormous increase of weight borne beyond what could have been dreamed of when they were first prepared, no sign of subsidence of any kind was discernible, though periodical tests for it were made, and the structure was carefully watched.

Building Declivity.—The declivity of the keel in building was $\frac{5}{8}$ inch to the foot, which is usual for a ship of this size, and that of the groundways, or foundation on which the cradle carrying the ship slides, was $\frac{5\frac{1}{4}}{8}$ inch to the foot. The longitudinal section of this surface was a circular arc, and had a "camber," or round up, of 9 inches in a length of 300 feet. This prevented the groundways becoming hollow under compression due to the weight of the ship and cradle, and so increasing the difficulty of launching, though there is perhaps no absolute necessity for this in naval yards where the floor of the slip is of granite or other hard stone upon a thick bed of concrete. It is however desirable that the form of the groundways should have some effect in holding the ship just before launching, and this varies with the position decided on for the top of the camber. Dockyard practice in this respect differs, and this point is sometimes at

mid-length, and in other cases at two-thirds the length of ship from the bow, or even at the after perpendicular. The declivity of $\frac{5\frac{1}{4}}{64}$ inch to the foot, referred to above, is the gradient of the tangent to this curved surface at the top of the camber, and the holding tendency is greatest the farther aft the tangent point is In the "Ocean," this point was at the aft side of stern post or after perpendicular.

In launching, the fore end of the straight part of the keel approaches the bottom of the slip in each foot of movement approximately by the difference between the launching and building declivities, viz., $\frac{5\frac{1}{4}}{64} - \frac{5}{8}$, or $\frac{1\frac{1}{4}}{64}$ inch, and as the distance from the fore end of the keel to the after end of the straight floor of the slip was 348 feet, this drop of the keel was $\frac{1\frac{1}{4}}{64}$ inch $\times$ 348, or 5 feet.

This consideration, and the clearance between the keel and the bottom of the slip at this point, generally from 1 foot to 2 feet, determines the height at which the foremost block shall be laid for building, and taken in connection with the building declivity, enables the blocks to be laid correctly, in view of the launching conditions. It is further necessary that this height of blocks should be sufficient to allow room on top of the groundways for the section of cradle shown in Fig. 15, Plate 90, including the bilgeway, the wedges or "slices," and the solid timber between them and the ship which is known as "stopping up," and had a minimum depth of about 6 inches.

The length of the groundways must be such as to secure that the ship and cradle shall not tip about their after end, and to determine this, certain calculations were necessary, the results of which are shown in Plate 86.

Calculation of Ship's launching weight.—The approximate date of the proposed launch determined the time the ship would be upon the slip, and the local circumstances as to available labour, coupled with building experience, enabled an approximation of the launching weight to be made. The proper progress of the ship fixed the parts which made up this weight, and thus it was possible to calculate in detail the weight of the several parts, and the positions of their centres of gravity. The weight calculation is

much simplified when, as is usual, a record is kept of all weights put on board. The total weight, and the position of centre of gravity, both vertically and horizontally, were thus obtained, and were easily corrected as the actual date of launch approached, when a closer approximation to the launching weight became possible.

The probable height of tide was given by the tide tables, and was drawn upon the profile of the ship as she lay on the blocks, Fig. 3, Plate 87. The displacement was calculated to lines parallel to this at any convenient distance, say 2 feet, which, as the ship was launched at a declivity of $\frac{51}{64}$ inch to the foot, corresponded to a travel down the ways of $\frac{2 \times 12 \times 64}{51}$, or about 30 feet, and this is the distance apart of the calculated ordinates giving the curve of buoyancy, Plate 86. The position of the centre of buoyancy was also estimated for the displacement to each waterline. These calculations assumed that the ship did not lift off the groundways as the after part became immersed, and it is also clear that the trim differed widely from the water-borne condition, because the keel was at a declivity of $\frac{5}{8}$ inch to the foot, and in a length of 390 feet this gave a difference of draught at the fore and after perpendiculars of $\frac{5}{8} \times \frac{390}{12}$ feet = say 20 feet 4 inches; while the trim by the stern when the vessel was afloat was only 3 feet, and her fully laden condition is designed for an even keel.

The results of these calculations, and the moments of weight and buoyancy about the after end of the ways and the fore poppet are plotted in Plate 86, where the abscissae represent the travel of the ship down the ways. The weight being constant is shown by a straight line parallel to the base. The curve of buoyancy intersects this at a point A after the ship has travelled 337 feet, when she is fully water-borne.

The centre of gravity of the ship was over the after end of the ways when she had moved 277 feet, when of course the moment of weight about this point was zero, while there was then a large positive moment of buoyancy, which was maintained and increased relatively to the moment of weight until the ship was fully afloat. There could therefore be no tipping motion while on the ways.

Although when the weight of the ship was taken on the cradle, the pressure per square foot on the groundways was not uniform, it only varied with the relatively small variation in the weight of the ship per foot of length as built at time of launching, when generally there is but little local concentration of weight due to such fittings as armour, machinery, &c. As buoyancy is gained in launching, a point is reached when the fore end of the cradle is alone in connection with the groundways, and it is there the local stress in launching is greatest. This is shown in Plate 86, where the moment of weight about the fore poppet being constant is represented by a straight line parallel to the base, and the curve of moment of buoyancy about the same point intersects it at a point B, corresponding to a travel of 302 feet when the stern of the ship commences to lift. The compressive force on the fore poppets at this moment is shown by the difference of ordinate CD between the curves of weight and buoyancy, and was equal to 1,320 tons, or 660 tons on each poppet, which had an area of 25 square feet, and therefore bore momentarily a stress of 26·4 tons per square foot. The mean pressure per square foot of bearing surface of the cradle between the fore and after poppets when in position on the slip differs considerably with different ships, ranging from about 1 to 3 tons, which is very seldom exceeded. In this instance it was 2·5 tons.

While it is not generally necessary with warships to determine whether they will have stability in the launching condition, because they are designed to be stable however light, yet such a calculation is made, and both the vertical position of the centre of gravity and the metacentric height are ascertained. The latter in this case was 12 feet.

The trim of the ship when afloat was also estimated, and showed that she would not be fully water-borne when the cradle left the end of the groundways, but would drop about 4 feet, for which there was ample depth of water.

The details of the structure of groundways and cradle, and the internal shoring of the ship to enable the strains developed in launching to be effectively distributed and safely borne, are described in the following paragraphs.

Groundways.—The groundways were 427 feet long and 6 feet 6 inches wide, and were laid on transverse blocks of oak in wake of each "land tie," or wood foundation of the slip spaced about 5 feet 9 inches apart. Between the oak blocks were two of fir equally spaced for about two-thirds the length of the slip, until near the position of the fore poppet already referred to, where the stern of the ship commences to lift. Below this, the blocks were of oak or teak, laid side by side. The upper surface of the blocks was trimmed throughout to the camber, and covered with 5-inch teak plank, secured with $\frac{3}{4}$-inch bolts, 9 inches long, rag-pointed, and punched down below the surface at least $\frac{3}{4}$ inch, to obviate all danger of their protruding under the compression of the ways and obstructing the launch. The butts of these planks were well distributed, and were bevelled, as shown in Fig. 8, Plate 88, to facilitate the travel of the cradle over them. The foremost planks in each strake were made as long as possible, dowelled into the blocks, and extended well abaft the fore end of the cradle. Through these planks was bolted the large cleat A, Fig. 4, Plate 87, which formed a base for the pressure of the hydraulic pumps, provided for pushing the ship off, if necessary. On the outer end of these groundways, a "ribband" A, Figs. 7 and 9, Plate 88, 12 inches by 10 inches, extending the whole length of the ways, was fitted. It was of fir except the upper 30 feet, which were of best English oak. The general security was $3\frac{1}{2}$-inch wood dowels, about 5 feet apart for about 300 feet down, with intermediate bolts 1 inch in diameter, except at the fore end where they were $1\frac{1}{8}$ inch. The plank of the groundways on which the ribband rested was also dowelled to the transverse blocks in wake of the land ties below it, as well as bolted like the other plank. The oak ribband, whose fore end took the thrust of the dog-shore, was dowelled to the plank, and bolted alternately through it to each transverse block of the groundways, and had a steel shoe at the fore end whose faying surface against the dog-shore was planed, B, Fig. 7. This ribband was laid so that when the cradle was in position there should be a clearance between the two varying from $\frac{1}{2}$ inch at the upper to $2\frac{1}{4}$ inches at the lower end of the ways. This provided against the cradle jambing between the ribbands

LAUNCHING OF A BATTLESHIP.

Fig. 1. *H.M.S. "Ocean."*

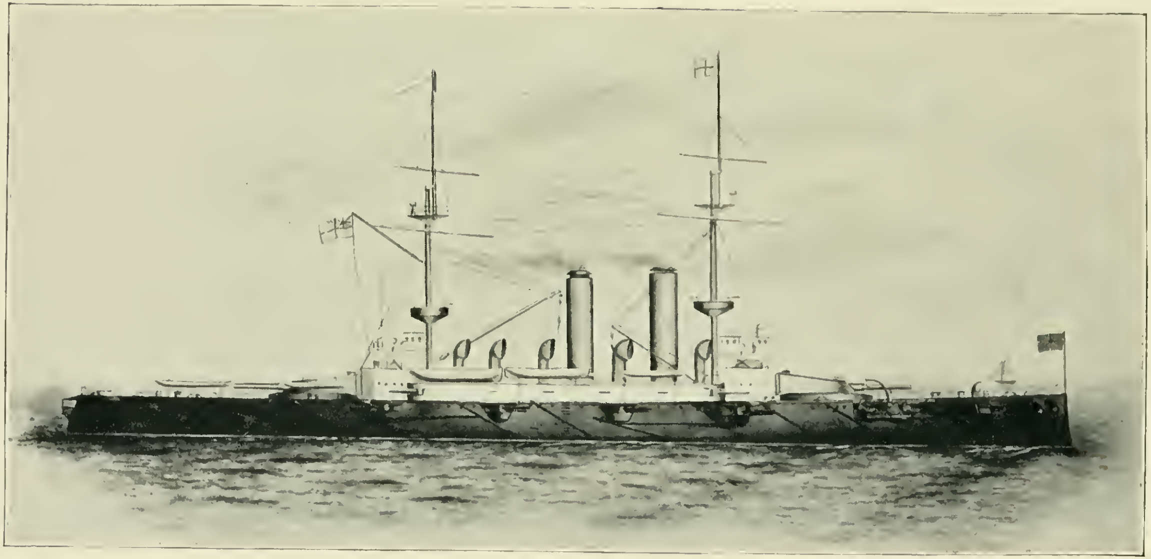


Plate 85.

LAUNCH OF A BATTLESHIP.

Fig. 2. *Battleship Launching Curves.*

Weight of Ship as launched 7,110 tons

Rise of tide 15 feet.

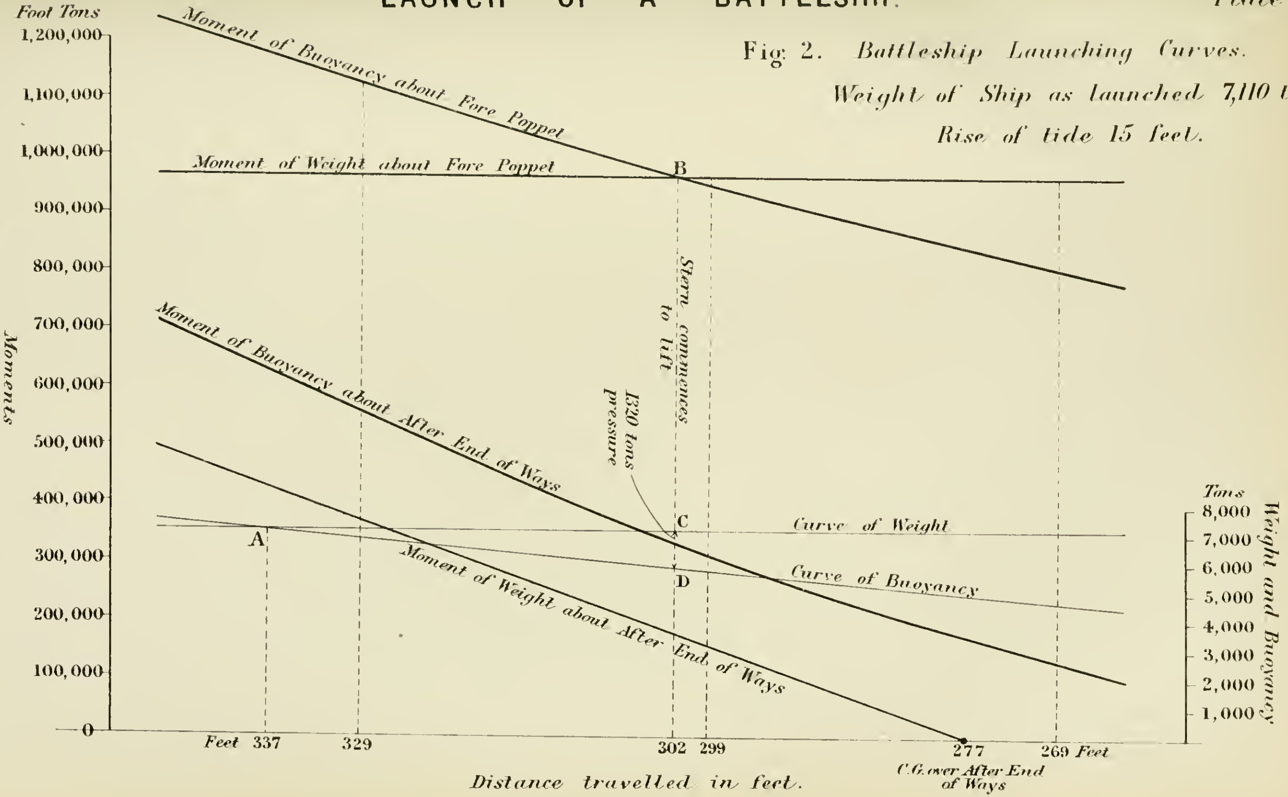


Plate 86.

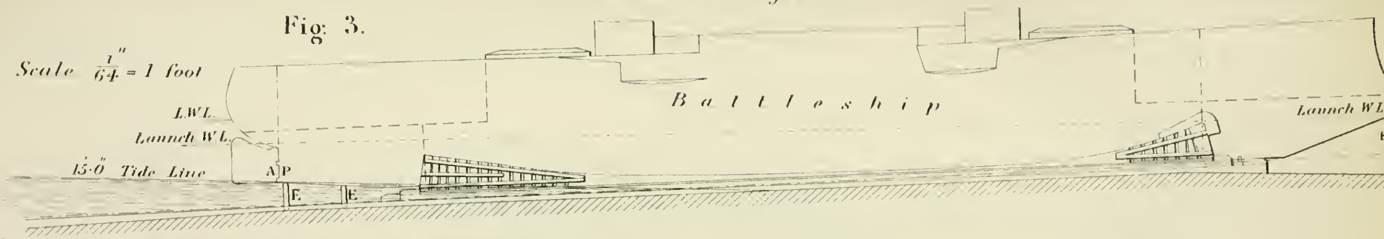
LAUNCH OF A BATTLESHIP

General Arrangements.

Plate

Fig: 3.

Scale $\frac{1''}{64} = 1$ foot



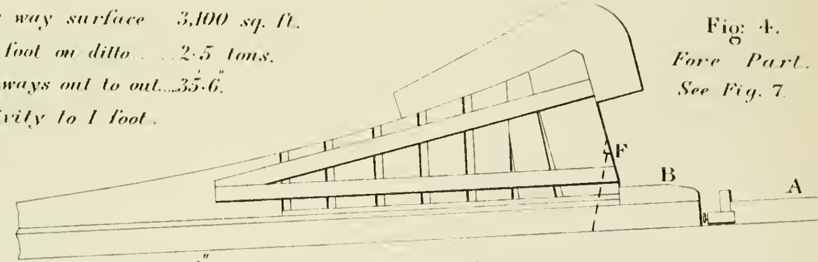
Launching weight 7,110 tons. Area of Sliding way surface 3,100 sq. ft.

Launching draught $\left\{\begin{array}{l}14.5'' \text{ forward.}\\ 17.5'' \text{ aft.}\end{array}\right.$ Pressure per sq. foot on ditto . . 2·5 tons.

Camber in Groundways 9" in 300 feet. Spread of Bilgeways out to out...35·6".

Tangent to Groundways at After Part $\frac{51''}{64}$ declivity to 1 foot.

Fig: 4. Fore Part. See Fig. 7.



Scale $\frac{1''}{16} = 1$ foot.

Fig: 5. Aft Part. See Fig. 12.

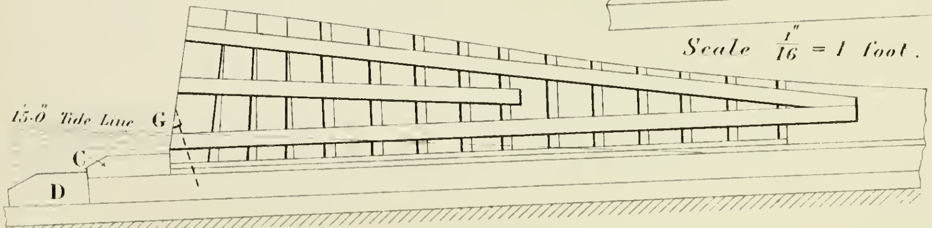
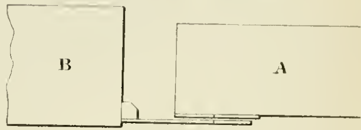


Fig: 6. Fitting for measuring "Draw" of Ship.



Scale $\frac{1''}{8} = 1$ foot.

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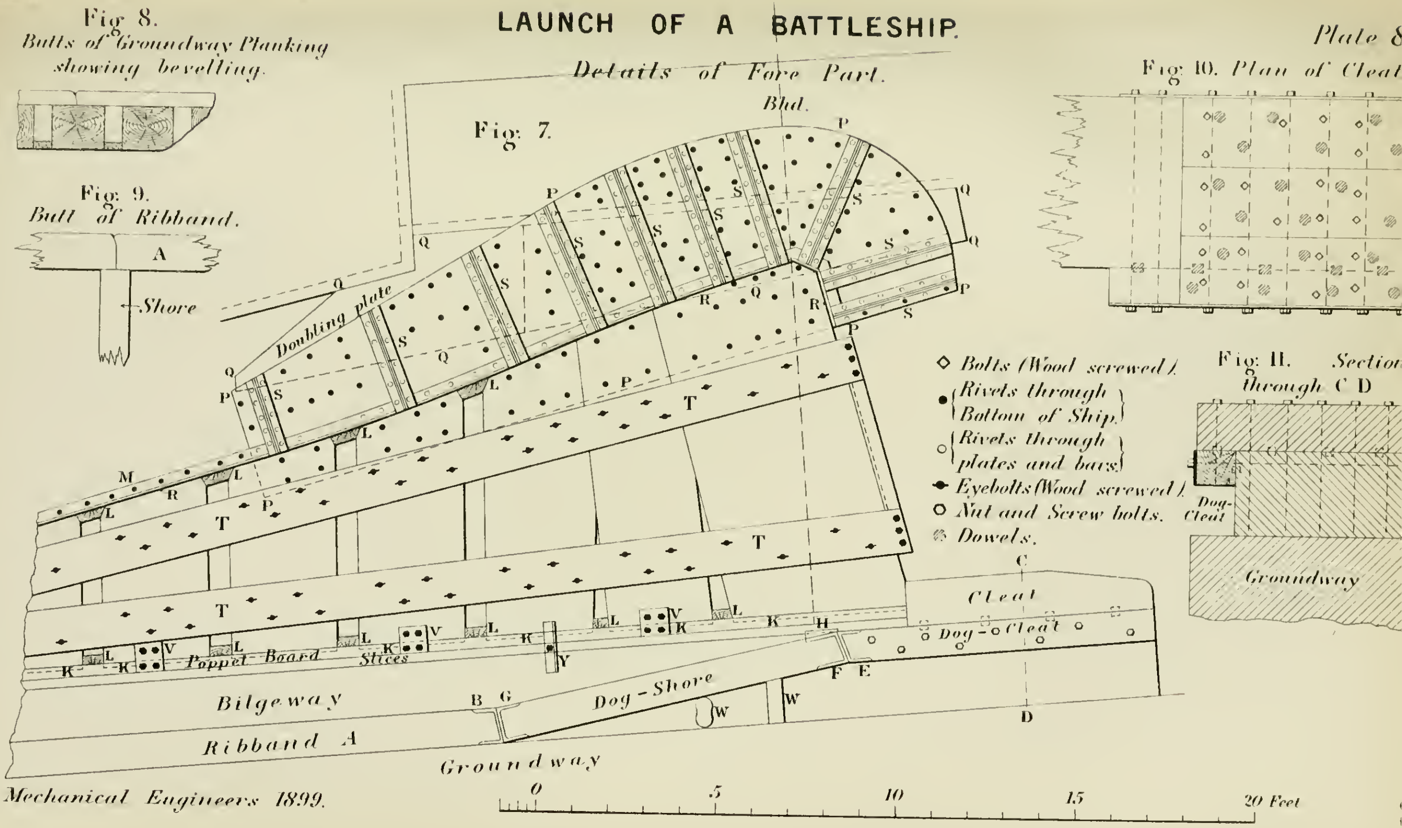
LAUNCH OF A BATTLESHIP.

Plate 8



LAUNCH OF A BATTLESHIP.

Fig: 13.

Section of Cutwater through AB

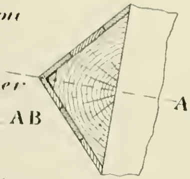
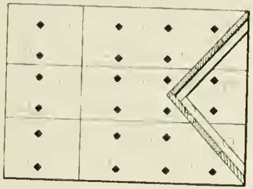


Fig: 14.

Plan of Cleat C.



Details of After Part.

Fig: 12.

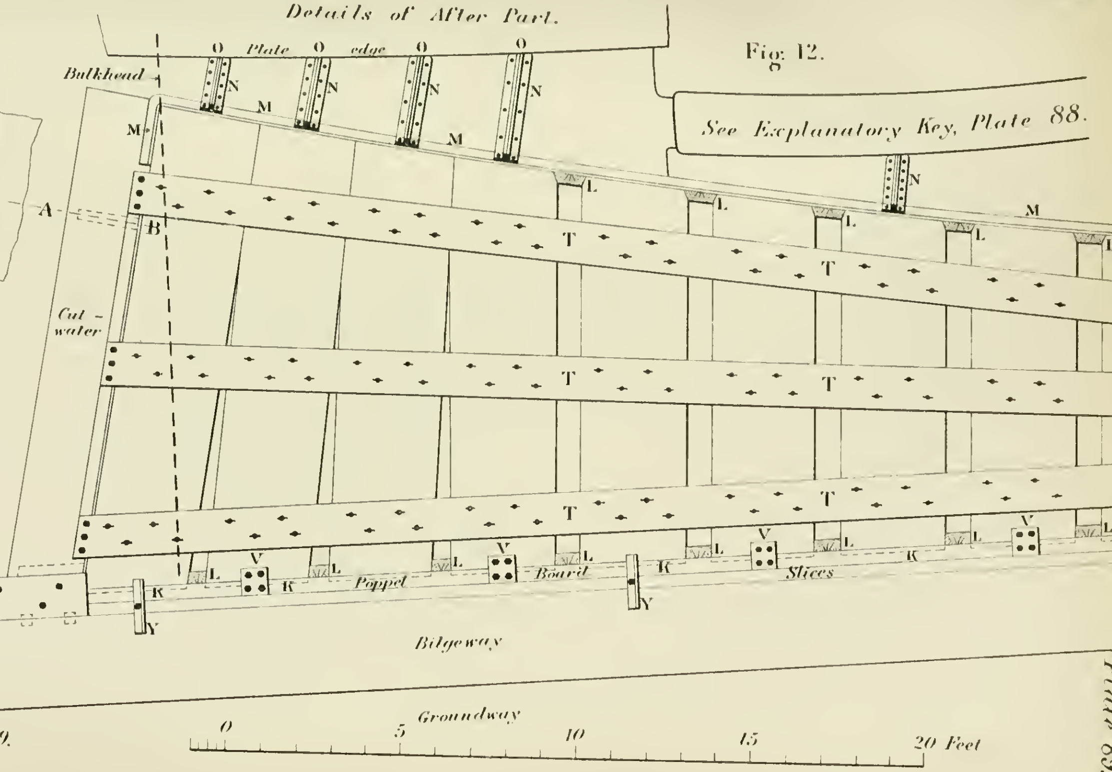
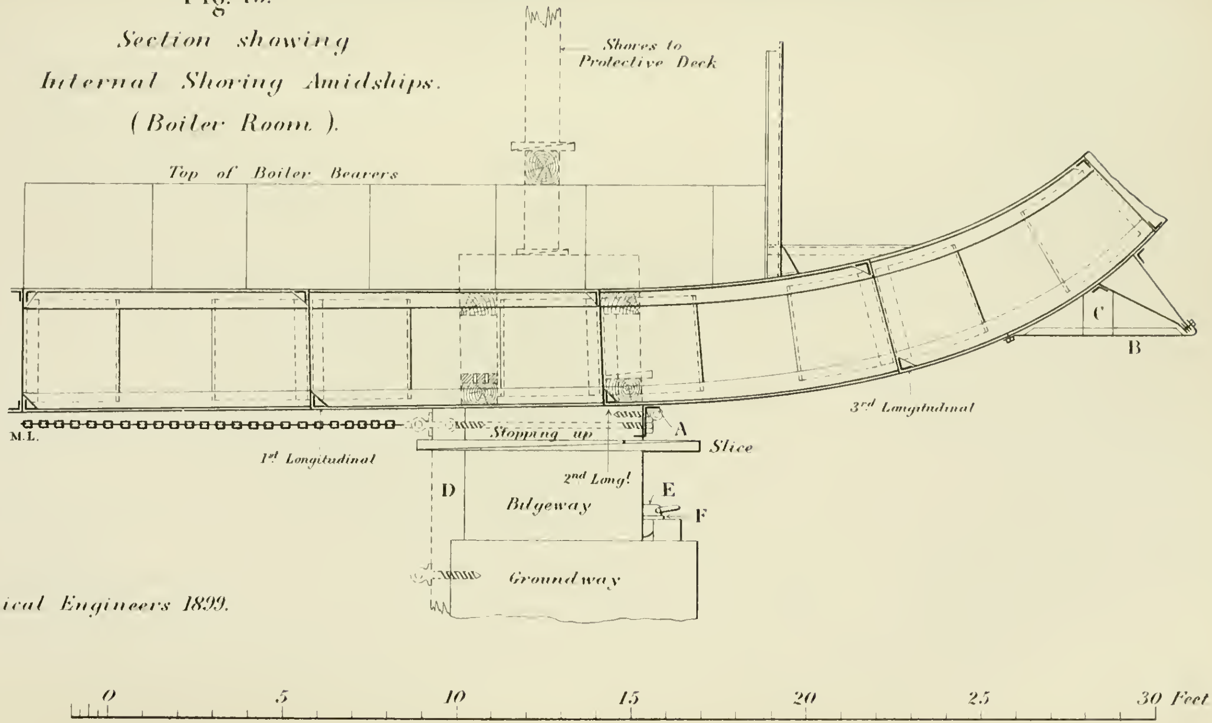


Fig: 15.

Section showing Internal Shoring Amidships. (Boiler Room.).



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Sections at Bulkhead.

Fig: 16.

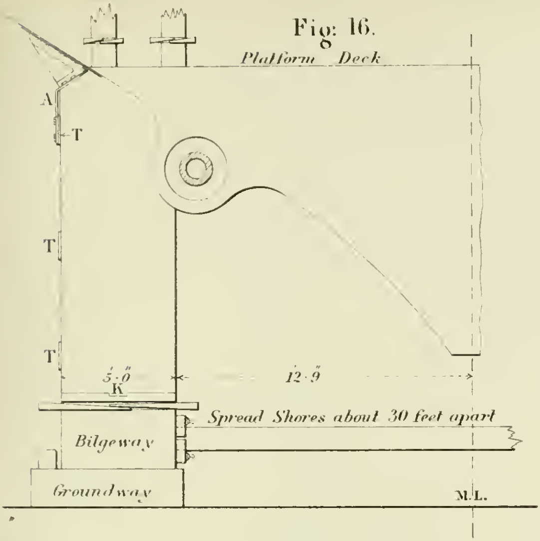
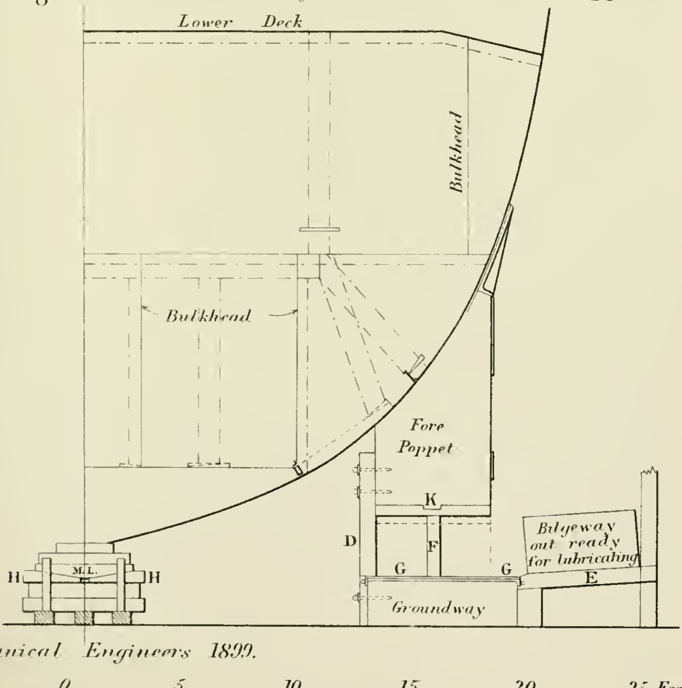


Fig: 17.
End of Spread Shore.

Fig: 18. *Internal Shoring in wake of Fore Poppet.*



Mechanical Engineers 1899.

as the ship went off, and the increased clearance at the lower end gave play for some small amount of swerving on the ways if the tide caught the ship before she was fully afloat. To resist the tendency of any such movement to carry away the ribband, each piece was shored not only at the butt, but also in mid-length, the shores being about 10 feet apart in wake of the cradle and 20 feet below. To prevent the shores which are fitted below high water from lifting under the action of the back wash as the ship went off, they were bolted to the groundways and lashed to the land ties of the slip at their outer ends. The three ribband shores at the fore end of the cradle were only 5 feet apart. The outer ends of all these shores butted against the solid masonry at the sides of the slip.

Cradle.—The general construction and component parts of the cradle will be understood from Plates 87 to 91 inclusive. The fore end of it was about 65 feet abaft the stem, and the after end at the extremity of the inner shaft tube, both being in wake of one of the main transverse bulkheads. Resting on the groundways are the bilgeways, solid timber structures of Dantzic fir, 310 feet long, 5 feet wide, and 2 feet thick, the lower surface being faced with 4-inch teak, called the "sliding plank." The fir section of 20 square feet was made up of four baulks with plain butts, the several lengths well overlapping and being bolted and dowelled together. The teak sliding plank was fastened with $\frac{3}{4}$-inch rag-pointed bolts, 8 inches long, the heads being punched below the surface at least $\frac{3}{4}$ inch, as described for the fastenings of the groundways, and for a similar reason. The ends of the bilgeways were built up by cleats, B C, Figs. 4 and 5, Plate 87, and thus formed stops for the heels of the end poppets. As the fore end of these bilgeways had to bear considerable stress, the cleat was of English oak the full width of the ways and strongly bolted to them, and on its outer side was fitted the dog-cleat of English oak, 1 foot square in section, fastened not only with dowels, but with $1\frac{1}{4}$-inch galvanised bolts passing right through the cleat, the heads bearing on a steel face-plate to the dog-cleat $\frac{5}{8}$ inch thick, and the points hove up on a similar plate, as shown on plan and section through CD, Figs. 10 and 11,

Plate 88. The after end of this dog-cleat was fitted with a steel shoe E similar to that at the fore end of the ribband. The space between these two points was filled by the dog-shore of African oak, 10 feet long and 1 foot square in section, having a steel shoe at each end F G similar to those it bore against.

It was this shore on each side which, with the few blocks remaining under the keel just before launching, and the friction of the grease on the ways, prevented the ship from being launched. Fig. 7 shows that the shore was cut at the fore end to such an angle that it cleared itself as it fell. A trial of this is always made when the shore is first fitted, and before any strain comes upon it, by letting a dummy weight fall upon it. The wedge-shaped steel face H on top of the dog-shore, immediately under the weight, had its upper surface square to the direction of the blow, the full effect of which was thus transmitted to the shore. While the exact resistance to be overcome in knocking away the dog-shore cannot be determined, a rough estimate on the safe side may be made by resolving the weight of the ship parallel to the thrust of the shore, and assuming that the blocks remaining under the ship and the grease upon the ways bear no part in resisting this. We thus get a crushing force on each shore of about 240 tons, and taking the coefficient of steel on steel as 0·3, and allowing that the shore clears itself after about $\frac{1}{2}$ inch of travel, which is really the case, we get—

$$\text{Work to be done} = 240 \times 0{\cdot}3 \times \tfrac{1}{24} = 3 \text{ foot-tons.}$$

The work due to the fall of $\frac{1}{2}$ a ton through 17 feet, which was provided for, is $8\frac{1}{2}$ foot-tons, which, with the other assumptions in favour of the pressure to be overcome, gave sufficient margin for safety.

The remainder of the cradle above the bilgeways consisted of three parts, the stopping up (amidships) and the fore and after poppets. The stopping up, which, like the poppets, was of the full width of the bilgeways, namely 5 feet, consisted of solid Dantzic fir timber carefully fitted to the bottom of the ship and 192 feet long. The poppets varied from 15 to 25 square feet in sectional area, and were nearly vertical, except the first and last two or three, which stood rather more square to the surface of the bottom in a fore and aft direction. The heels of these poppets were steadied by tenons

9 inches wide and $1\frac{1}{2}$ inch deep, which fitted a fore and aft groove, KKK, Plates 88, 89 and 91, in the 6-inch poppet board of English elm below them; the spread of these poppets at the heel just above this board, and also at the head, was preserved by chocks, LL, Plates 88 and 89, but the end poppets, especially those forward, were close fitting from the head well down their length. The various pieces composing them were not only bolted together like the others but were also dowelled. Each set of poppets was connected together outside the cradle by steel "dagger" plates, TT, Figs. 7, 12, and 16, three aft and two forward, 14 inches wide and $\frac{3}{4}$ inch thick, secured to the poppets by Blake's screws, and extending far enough from each end to overlap and be fastened to the stopping up.

Between the upper surface of the bilgeways, and the underside of the stopping up and poppet board, was a space of $4\frac{1}{4}$ inches, in which the "slices" or beech wedges, 6 feet 6 inches long, were inserted when it was desired to "set up" the ship, that is, to take the weight on the cradle and off the blocks sufficiently to enable the latter to be rammed out.

To prevent the cradle falling outward at the head, a steel angle M, Figs. 7 and 12, was riveted to the bottom of the ship, extending from near the fore end to the extreme after end, where it was turned down over the aftermost poppet. The position of the after poppets, and the shape of the bottom there, gave their heads a much better bearing against the ship than was the case forward, and as the after end of the ship was soonest waterborne, and the poppets there were not subject to the great stress of those forward, it was not necessary to do more than support the angle referred to by the bracket plates shown at N N, Fig. 12, which in each case were continued as far as the projecting edge O O O of the bottom plate above. At the fore end special strengthening was necessary for reasons already stated, and is shown by Fig. 7, where the plate PPP was of $\frac{1}{2}$ inch steel, with a similar plate QQQ riveted at the back of it, and fitting closely between the projecting edges of the bottom plates above and below it, thus greatly stiffening the structure to resist shearing of the fastenings. Over the heads of the poppets, a $\frac{5}{8}$-inch steel plate RRR riveted to a $7 \times 3\frac{1}{2} \times \frac{5}{8}$-inch angle-bar, was

fitted and turned down over the fore end of the foremost poppet, the connection being stiffened by ten brackets SSS formed of $\frac{1}{2}$-inch plates and double steel angle-bars. All the parts of this plate and angle structure were most carefully fitted to each other and the bottom, the only connection to the latter being by 1-inch steel rivets through the plating between the brackets. The single shearing stress of each rivet is assumed as 20 tons.

This structure might yield in two ways, (a) by the shearing of all the rivets in the brackets and angle-bars over the heads of the poppets, or (b) by shearing all those through the bottom, and also those through the brackets and doubling plate. The pressure on the fore poppet when the stern began to lift has been given as 660 tons, and this may be resolved into a tangential stress of 585 tons, and one of 320 tons normal to the bottom. Assuming this tangential stress distributed by means of the structure over the area surrounding the heads of the foremost three poppets, we should have to shear about 120 rivets in case (a), giving a total shearing stress of $120 \times 20 = 2{,}400$ tons, and a factor of safety $= \frac{2400}{585} = 4 \cdot 1$, which is ample. Fracture in case (b) would need a shearing stress of $167 \times 20 = 3{,}340$ tons, or a factor of safety $= \frac{3340}{585} = 5 \cdot 7$.

In order that the two parts of the cradle should preserve their relative positions during launching, spread shores, about 12 inches square and ten in number, were fitted between them under the keel, and resting in English elm cleats secured to the bilgeways, Figs. 16 and 17, Plate 91. One of these shores was at each end of the ways, one opposite the fore end of the dog-shores, and the remainder divided the intervening length about equally. These acted as struts. Between them at the butts of the stopping up, spread chains were fitted as ties, setting up to $1\frac{3}{4}$-inch steel eye-bolts through the stopping up, the bolts being hove up on plates covering the butts on the outside of the cradle, Plate 90. These spread chains were not fitted in wake of the poppets.

No part of the cradle was attached to the bottom of the ship, and as it was fitted below the bilge-keel, and had a certain amount of buoyancy, it might leave the ship as soon as she was afloat and be

held under the bilge-keel, unless this were provided against. To keep it clear, T bars or double angles were fitted as shown at B, Plate 90, at intervals of about 15 feet, tapped to the bottom of the ship and bilge-keel, and having a wood strut C above each in the angle formed by the bilge-keel and bottom of the ship. The close fitting of the cradle, and the pressure developed in launching, generally make the cradle adhere so firmly that it must be pulled out by tugs, as it is necessary to remove it for the safety of the ship in docking. For this purpose, steel-wire hawsers were separately attached to the fore and after ends of the cradle, and to each piece of the stopping up, the ends of the hawsers being carried inboard on the upper deck till wanted.

Internal Shoring.—While the fullest use was made of the structure of the ship to prevent any alteration of form under the strains borne in launching, by having all possible pillaring complete, and all bulkheads and flats riveted off, it was necessary to provide some internal wood shoring, as shown in Plates 90 and 91. The spread of the cradle from out to out was 35 feet 6 inches, Fig. 16, which caused it to bear directly under one of the longitudinals for a great part of its length, Fig. 15. Short shores were also fitted, as shown, between the inner and outer bottoms, above the edges of the cradle, and a covering baulk was laid on top of the inner bottom, from which stout shores reached to the protective deck. The great strength of the framing between the inner and outer bottoms for the engine bearers, and that of the bearers themselves, which were complete, made special shoring at that part unnecessary, but for the remaining length of the cradle, and particularly abreast of the foremost poppets, it was provided, and at the latter place the structure was stiffened from one side of the ship to the other, Fig. 18. The total weight of these shores was about 90 tons.

Lubrication of Sliding Surfaces.—The whole of the work already described was completed a fortnight before the launch, when preparations were made for applying the lubricants to the sliding surfaces. For this purpose the whole of the cradle above the

bilgeways was temporarily suspended to the bottom, on the outside of the cradle by strips of ½-inch plate, A, Figs. 15 and 16, tapped through the bottom of the ship and screwed to the cradle. On the inside, wood struts, D, Figs. 15 and 18, 6 inches × 6 inches, resting on the bottom of the slip, and screwed below to the groundways and above to the cradle, kept the latter in position against the bottom of the ship. The poppet board was secured to the poppets, both inside and outside the cradle, by plates, VVV, Figs. 7 and 12, screwed to both, and left in position until the ship was afloat, which prevented the board from leaving the poppets and sinking, as being of English elm it might do. The ribband on the outer edge of the groundways was then removed, and 5-inch plank, E, Fig. 18, fixed at intervals from 20 to 30 feet, with its inner end at top level with the top of the groundways, and sloping up and outward. The bilgeways were next hauled by steam winches on to these supports, and the remainder of the cradle was temporarily shored up from the groundways, F, Fig. 18. After a careful inspection of these surfaces, the lubricants were applied first to a short length of the ways, which was coated to the required thickness, and then loaded over a portion of its surface to the mean pressure of 2·5 tons per square foot by ballast; this load was launched, and tested the adhesiveness of the lubricant to the groundways and its adaptability generally for its work. The exact position of the bilgeways having been razed in on the groundways for fitting purposes, wood battens ½ inch thick were nailed to these lines, and the space between them coated with Russian tallow applied hot until a solid coating ⅜ inch thick was obtained. It is sometimes an advantage to mix beeswax with the tallow, in order to assist the cohesiveness of the lubricant and prevent it from cracking and caking. On this a coating of "slum" was placed, made up of Russian tallow and train oil boiled together and well mixed in the proportion of four gallons of oil to 1 cwt. of tallow, being one part oil to two of tallow. This was not applied hot. The proportion of oil varies with the temperature of the atmosphere, being less in hot than in cold weather. The surface of the slum was irregularly grooved, after which train oil was poured upon

it, and finally soft soap scattered in patches throughout the length of the cradle. The under surface of the bilgeways was coated with Russian tallow similarly applied, but only to a thickness of about $\frac{1}{4}$ inch, on which the slum was placed. The side of the ribband next to the bilgeways was also thickly coated with slum, and the narrow space between them sprinkled with oil. Across the surface of the groundways, forty grease irons, GG, Fig. 18, to keep the bilgeways clear of the groundways while being hauled back, were then placed in pairs and steadied on the inside of the cradle by workmen, until the bilgeways were hauled again into their proper position, and fayed against the struts previously described as supporting the cradle against the bottom of the ship. The grease irons were withdrawn, the battens removed, and the long beech slices, of which about 1,300 were used, were inserted between the bilgeways and upper part of the cradle, except those below high water, which were not put in until it was necessary to drive them, and so were kept dry. The temporary struts and angle supports to the cradle were next removed, the ribband on the outer edge of the groundways was replaced, fastened, and shored, the holes through the bottom of the ship were plugged, and the cleats on the bilgeways replaced and bolted. A large cleat, D, Fig. 5, Plate 87, was also bolted to the groundways at the lower end of the cradle, to prevent any premature sliding movement. Ten steel keys, E, Fig. 15, Plate 90, on each side, varying regularly from $\frac{1}{2}$ inch to $1\frac{3}{4}$ inch in thickness from fore to after end of bilgeways, were then inserted at equal distances between them and the ribband, and maintained them in position. Battens F were nailed over this groove to prevent any substance getting in which might obstruct the launch. The remaining slices were inserted, the dog-shores were placed, and two "triggers," WW, Fig. 7, put beneath each, that with a plain bevelled end preventing the shore from falling, and the other with rounded end serving the same purpose when just before launching the former was removed. Between the slices at intervals were twelve steel angles, YY, Figs. 7 and 12, on each side of the cradle, connected by bolts hove up with nuts, and these helped to keep the sides of the cradle in position and flush with those of the bilgeways.

Setting up the Ship.—Preparations were then made for "setting up" the ship. This operation is generally begun the day before the launch, the after portion only being dealt with at that time, say for about one-fourth the length of the cradle. For this purpose the slices were manned both inside and outside the cradle by shipwrights with heavy mauls. The shores at this part were also manned and kept effective as the setting up proceeded by tightening the wedges under them. At a given signal the whole of the men struck together. The strain on the building blocks was tested at intervals by striking the wood wedge blocks, HH, Fig. 18, Plate 91, of each tier until it was clear that they had been relieved sufficiently to enable them to be readily removed. This removal followed immediately upon the conclusion of the setting up, and the building shores under the bottom inside the cradle were also taken away, the remaining shores outside the cradle being roped at the head, and the ropes carried inboard in readiness for lowering them on the launching day after completing the setting up. As the blocks were removed, "skeg" shores, EE, Fig. 3, Plate 87, rounded at each end, were placed under the keel at intervals, to assist in supporting the overhanging part of the ship beyond the cradle and the blocks left standing. These shores are generally left in position until the ship is launched, the form of their ends making it easy for her to trip them as she moves. The drying and lubrication of the ways below the cradle was carried out on the morning of the day of launch as the tide ebbed, and finished as it rose. The completion of the setting up commenced at about the same time and somewhat abaft where it was left the day before, and was continued until near the fore end of the cradle. It is not usual to set up the extreme forward end but only to tighten up the slices there as necessary to give them a proper bearing. Three or even four slices were allotted to each man in setting up. When this work was finished, the heads of the slices were roped together, as they have some buoyancy and might otherwise float away singly when the ship was launched. The remaining shores between the cradle were removed, and the dog-shores were tightly set by driving a thin steel wedge between them and the fore end of the ribband on the groundways. Additional

security was given to the foremost and aftermost poppets by driving two long-bolts through each into the bilgeways, F, Fig. 4, and G, Fig. 5, Plate 87; and to somewhat lessen the resistance, a cut water, Plate 89, was fitted against the aftermost poppet. The remaining building shores were then knocked away, commencing from forward and working regularly aft, as the foremost shores tend to push the ship down the slip, while the after ones act as struts against this.

The completion of the setting up was effected in time to enable all these shores to be got away before the rising tide reached the aftermost. It frequently happens that as the remaining keel blocks are removed, and the ship settles down on the cradle, she moves slightly or "draws," and before knocking away these blocks, means are adopted for measuring this movement by fixing two battens parallel to but not in contact with each other, one to the fore end of the sliding ways, and the other to the side of the fixed cleat at the fore end of the groundways, and with their upper edges in the same plane. Across the edge a line is transversely drawn, and whatever slight sliding motion takes place is shown by the distance between this line on the fixed and the moving batten, Fig. 6, Plate 87. A corresponding "tell-tale" was also fitted to the stem of the ship upon the launching platform. The difficulty of getting the keel blocks away varies greatly with different tiers, depending partly upon unequal crushing of the blocks during building, and the extent to which the ship is set up and afterwards settles upon the cradle and blocks. Generally the excessive pressure is only upon a few tiers of blocks, and, as the hour of launching draws near, may be only upon one tier. As a rule, upon the day of launching, the blocks are only removed sufficiently in advance of the tide to permit the work to be done. This remark applies also to the removal of the bilge-cleat at the after end of the bilgeways, and to that of the steel keys and battens on top of the ribband. Should the ship be lively and draw to any extent, some tiers of blocks would be replaced and the ship would be allowed to trip them in launching. If however the tell-tales show no sign of movement in the ship, the removal of the blocks would proceed right up to the time of launching, and it might even happen that no blocks would remain

under the keel when the dog-shore fell, but this extreme is not usual. Experience must guide in this matter in connection with the circumstances of each case, and ships of the size now described have been launched with as many as nine-and-twenty tiers of blocks standing, and with as few as one. The removal of the blocks is facilitated by the method of building them; the wedge blocks, H, Fig. 18, Plate 91, generally soon yield to the blows of a ram, but in addition to this, the thin top or "cap" block is usually of some straight grained but fairly hard wood, such as teak, which has to be split out by steel wedges when the ram fails. The use of gunpowder for this purpose has been known in a private shipbuilding yard.

Hogging and Sagging.—After the ship was set up, means were taken to ascertain how much the elasticity of the structure allowed her to alter form, both longitudinally and athwartships, from the landborne to the waterborne condition. As great a length as possible on the upper deck was chosen, and three vertically-adjustable sight battens were fixed, one toward each end and one about amidships. The edges of the battens were carefully sighted, so as to be in one plane, and the positions were marked upon the fixed framework carrying the sights.

Similar adjustments were made after launching, and the differences afforded a measure of the droop of the ends of the ship relatively to the middle, or *vice versâ*, known as hogging and sagging respectively. Athwartship observations of this kind are only made in the ships of greatest beam, and seldom show an appreciable movement. In the case of the "Ocean," the "breakage" by hogging in a length of 312 feet was only $\frac{5}{16}$ inch, and in a breadth of 61 feet, nil.

Freeing Dog-shores.—Each weight of 10 cwt. for freeing the dog-shore was placed in position on the day of the launch at the top of a shoot which allowed a drop of 17 feet. The weights had been suspended for ten days previously by the white manilla rope to be severed at the moment of launch, so that the rope had been fully stretched before the weight was finally put into position. This rope

was led over a sheave at the top of the shoot to the front of the ship's ram, and lashed across a wood chock there. The framework of the shoot, consisting of steel angles at the corners, and so having open sides, admitted readily of the insertion of a shore to take the strain of the weight off the rope until the last moment.

A tide gauge was fixed at the after end of the groundways, and the height of water over the groundways was recorded in sight of the launching platform every quarter of an hour during the last hour and a half before launching. The number of the blocks remaining under the keel was similarly recorded as each tier was removed.

It is not often that the blow of the weight fails to free the dog-shore and release the ship, but in case of failure, men are ready to cut away this shore with axes until its weakened section causes it to yield. This operation is dangerous not only to the men, but may be so to the safety of the ship if one shore yields before the other.

To assist the ship to start on the fall of the dog-shore, a hydraulic pump of 150 tons pressure was placed on each side at the fore end of the bilgeways, and one of 80 tons in reserve. There was also one of 500 tons directly beneath the stem, to ease her off the groundways. Special care was taken to test the efficiency of these pumps, both before and on the day of the launch, and also to see that they were not exerting any pressure until the dog-shores had actually fallen.

Watertight Compartments.—As the work of building progressed, all compartments below the calculated launching draught of the ship, and as many more as possible, had been completed and tested for watertightness, and the permanent doors or other means of access were also in place and closed before launching. All Kingston valves, sea-suctions to pumps, inlets and discharges through the bottom, were tested and certified to be tightly closed. Two 9-inch Downton's pumps were completely fitted on board to give some power of ridding the ship of water if necessary, and the sluice-valves on bulkheads, and water-courses to the pump suctions were all seen to be clear. Men were launched in the ship to make an inspection of all compartments below water as soon as she was afloat, and report the result.

The Launch.—All being thus in readiness, the tide gauge showing sufficient water, and the harbour reported clear, the men removing the blocks were withdrawn, the shores supporting the weights were taken out, the triggers beneath the dog-shores were removed, and the rope holding the weights was severed, knocking away the dog-shore which together with the weight was pulled clear of the ways, and the ship was free.

No observation of the launching velocity was made, but as a series of such records for various ships launched on the same groundways with different building declivities and launching weights would furnish useful information, it may be possible at some future time to supplement the present Paper by a discussion of such particulars.

The speed in launching is checked in many private yards by heavy anchors bedded in the ground, and with lengths of cable ranged alongside the groundways, the ultimate tautening of the cable checking the ship. This is suitable and necessary where the ship is launched into a channel of comparatively small extent relatively to her length, and to the distance she would travel if free; but the ordinary means of dropping anchor are adopted in the Government yards, where the channel is ample enough for the ship to go well out and swing up into the tide when the cable is slipped.

If possible the wood cradle is pulled out before berthing the ship, but generally this is done more at leisure on days subsequent to the launch, and before docking.

In conclusion, the author adds the hope that the particulars given, apart from any interest they may have for the members of the Institution, will be of benefit to the students of naval construction in training at the Royal Naval Engineering College at Devonport, and to many others in the dockyard, who, so far as the author is aware, will find for the first time embodied in a connected form, a detailed account of the principles and the work involved in the launch of a large battleship.

Discussion.

The President said that when the members visited the Dockyard that afternoon they would see on the slips H.M.S. "Bulwark," which had been building for about four months, and he would leave them to judge whether there had been a good four months' work done. She was approaching the stage when the launching arrangements would be taking place, so that the Paper had a direct bearing on what would be seen that afternoon.

Mr. John I. Thornycroft, Member of Council, felt it was his duty to give testimony to the admirable Paper of Mr. Champness, and to mention that in it there was not only given the general features of the launching of a battleship, but all the necessary operations to ensure success; and a relative sequence was described, so that the members had some ideas and probably felt that they ought to be able to launch a ship themselves. He took it that the operation described in the Paper was one in which a very small mistake might lead to a very great sacrifice, and he was glad to hear that preparations were made in such good time for completing the work. He thought the members were greatly indebted to the author for the care taken in the preparation of the Paper, which would be of great value to the Institution.

Mr. George Crocker said the author had stated that, in the government dockyards the slips had been used so frequently and for such a length of time for launching ships, there was little or no necessity for cambering the ways. The author also stated (page 346) that he was desirous that the points he had put forward should be brought before the notice of the students of naval construction with a view to their improvement. He himself was anxious to call attention to the fact that, if there was no necessity for cambering the ways, there were certain disadvantages which were likely to cause a great deal of trouble and difficulty at the time of launching. In the Paper it was stated that cambering, or the

(Mr. George Crocker.)

arching up of the ways for the "Ocean" amounted to as much as 9 inches (page 330). The great weight of the "Ocean" and her length made it necessary that a very small declivity should be given to the ways; the arching up further tended to reduce that declivity, and, seeing that the ship was built on blocks having a slope 5-8ths inch per foot, with no risk of her running away at such an inclination, whilst that of the ways themselves only amounted to a little more than 3-4ths inch over their whole length, there was but little latitude between them.

By cambering to the extent of 9 inches on 300 feet, the difference of inclination between blocks and ways was reduced by about 2-64ths inch off the 51-64ths, and had the top of camber been placed at mid-length of ship, as stated to be sometimes the practice, the effective declivity at upper part of slipway, where alone the building blocks remain at the time of launching, would have been about 47-64ths only. In such cases it will be seen cambering is rapidly taking away the capability of the building blocks to hold the ship. There is an important moment at every launch—when the dog-shores have fallen, and it is desirable the ship should start at once under the influence of gravity down the inclined ways. The inclination must be greater than 5-8ths inch per foot, but the higher limit in long heavy ships is very little above that amount, and it is therefore important to impress on students of naval architecture that, if no advantages are to be gained by cambering, the proper course is to give little or none.

Professor ROBERT J. SCOTT said that he desired to ask a question; he knew little regarding the launching of a ship, and approached the subject without any preconceived ideas. He thought most people would agree that the most awkward questions often came from those people who knew really nothing about a subject. He was very much struck on going round the Clyde shipbuilding yards, and shipbuilding yards in other parts of the country, with the great care taken in the construction of the vessel, and on the other hand with what appeared to be the exceedingly temporary nature of the apparatus used for launching. It seemed to him that they had gone

on exactly in the same way as their forefathers did before them. They had very much the same apparatus and very much the same arrangement, and very much the same method of carrying out the work as was used when the old wooden ships were launched. It appeared to him—and again he was simply speaking as an outsider—more natural, when the very large amount of money at stake was considered, to prepare properly each shipbuilding yard for the purpose of launching, that was, to have permanent ways and to build the vessels on those permanent ways, and to have perhaps permanent carriages which could be mechanically formed to fit the hull of any ship, and launch the vessels upon those carriages. What he wanted to ask was, if there would be any objection to that mode of treating the problem.

The PRESIDENT said he might be permitted to say, as a contribution to the discussion, that it seemed to him a striking thing that in the Proceedings of the Institution there should be no previous record, so far as he could learn, of such an important operation as the launching of a ship. Whether that view was right or not, there was now no longer that complaint to make. The members of the Institution would now be able to find in their own Proceedings a most complete and detailed account of that operation. They had to thank Mr. Champness, who did not volunteer the Paper, for the labour of preparing it at a time when he was very much pressed with other work. In regard to the question put by Professor Scott, perhaps he might anticipate the author and say that, while it was true that shipbuilders were in many respects conservative, it was also true that they were open to suggestions, and that what appeared to be a continuance on ancient ways was not mere conservatism but the result of well-proved experience. Attempts had been made at novel means of launching. One such attempt was notorious: it was that of the launching of the Great Eastern, where a civil engineer of the highest ability undertook to launch a ship in a novel manner. It was not for him to say why the attempt did not succeed, as there might have been many causes contributing to that result. The problem to be solved in the launching of a ship weighing 7,000

(The President.)

tons was not an easy one. If members would turn to the Paper, he thought they would see that what had to be done was to lower a weight of 7,000 tons through 20 to 25 feet of vertical height, and put that mass safely into the water in a few seconds. It was a charming prospect, far surpassing that of the expanding piston which Brunel conceived in connection with the Atmospheric Railway, to imagine any shipbuilder devoting himself to the design of launching apparatus capable of very wide variations in its dimensions and adaptable to many types of ships. That was an interesting field of enquiry and fairly extensive. The outsider was apt to think of things as temporary and incomplete which were not so. There was no place in the world where launching was more difficult than on the Clyde, and there, although the launching apparatus might seem somewhat primitive, it served its purpose admirably. An accident in launching was of rare occurrence, and in these days, with the enormous increase in the launching weight and sizes of ships, it might be taken for granted, he thought, that, if there was any possibility of economy or increase of efficiency in varying those well-proved arrangements, steps would be taken to adopt them. There was no mechanical impossibility in designing launching apparatus, which would be capable of doing all that Professor Scott had spoken of, but his own experience led him to believe that it was better to retain existing arrangements. Of course there were many cases in which the groundways (the slides on which the ships move in launching) were permanent, or almost so. For instance, where a number of ships of approximately similar types were being built on the same berth, this was done. Into the technical part of the Paper he did not propose to enter, but he might say that there were simple principles on which success depended, and a departure from which not infrequently led to trouble, defeat, or to disaster. It was once his misfortune to stand an hour and a half under the bottom of a large battleship which was moving at the rate of 4 or 5 inches a minute, and yet could not be stopped. During that period the tide rose, reached its full height, and was rapidly falling before the launch was completed. The cause of the trouble in that case was afterwards ascertained to be a well-intentioned but

unfortunate change in the manner of dealing with the lubricant. What should have been oil had become soap, and the difference proved to be very serious. He remembered another case where a clerical officer, whose mind ran in the direction of economy, proposed to buy tallow at a cheaper rate for the purpose of using it in the launching of a battleship. His object was very good, but the officer who was responsible for that launch was not convinced that economy could be usefully practised in that direction. He therefore made two specimens of the launch, and weighted them exactly as they would be in the case of the actual ship; he then put them at the proper inclination, and used as lubricant in one case the tallow that he knew was good, and in the other, the cheap tallow. The launch with the good tallow was perfect; the other refused to move. It was better to spend a little money on such an experiment, than to try the cheaper tallow on the ship; and other tallow was procured. In those and many other ways they rested upon experience. The weights that could be safely taken per unit of bearing surface with layers of lubricants of recognized quality were known. Enormous weights had to be sustained upon those layers both before and during the launch. Regard must be had also to the circumstances of the time; a ship launched in the depth of winter was under different circumstances from one launched in the tropical weather sometimes experienced here. The matter required close attention, as Mr. Champness had properly said. But, in the main, the method of launching a ship as practised universally with regard to the preparation of the slipways, the cradle, and all the essential conditions, were devices resulting from centuries of experience, and he would be a very bold man indeed who went far away from them. The mechanical details varied, of course. In the launching of the "Oceanic," and some other ships, there were some modifications in the arrangements. The dog-shores, which Mr. Champness described (page 336), were replaced by other special appliances; but those details might vary infinitely. The main features of a safe launch, however, were not to be lightly changed from those which the experience of centuries had sanctioned.

(The President.)

The President then formally moved the sincere thanks of the members to Mr. Champness for the labour he had bestowed in the preparation of his Paper.

The motion was carried unanimously.

Mr. Champness in reply said he was very much obliged for the kindly reception given to his Paper. He did not know that on the merits of the Paper itself there was anything in particular for him to answer. He did not however give the reason put forward by Mr. Crocker for not cambering the ways, but stated that, for the purpose of preventing them from becoming hollow under compression, it was not necessary. He went on to point out the desirability of having a camber, from consideration of its effect in holding the ship just before launching, and this is the advantage obtained by cambering which it is not desirable to forego with heavy ships. He was not aware of any royal dockyard where heavy ships were launched without any camber to the groundways. If Mr. Crocker's point was intended simply to call the attention of the students, to whom he referred at the end of the Paper, to the fact of the particular arrangement of the camber, he had no doubt they would consider it, for they were very keen upon their work, and went very deeply into any question that came before them. The President had answered Professor Scott in the most powerful way that he could be answered. Anybody, who had had to do with the launching of a ship, knew that the main thing was to get the ship into the water, and if ships had been going into the water for centuries in a certain way, and a man was responsible for getting one more there, he naturally took the way that had been used successfully before, rather than make experiments which might cost him his reputation, if it did not cost him anything more. There was one other thing he might say in reply to Professor Scott. If he rightly understood the Professor, he had in mind something like a permanent cradle, which should be in position as the ship was built.

Professor Scott said it was more in the type of permanent ways or permanent foundations,—the lower ways.

Mr. Champness said that in that respect in the royal dockyards the lower ways were to some extent permanent. They did not renew the groundways for ships of very similar dimensions, but as there were differences in the beams of ships which might be launched from a given slip, and the spread of the ways was generally preserved about one-third of the beam of the ship, with very wide differences in the beams of the ships launched from the same slip there would have to be different groundways.

The President said he might be permitted to make one anecdotal statement. At the launch of the "Victoria" he stood by the side of Lord Armstrong, who was an engineer of some experience, and he assured the members that on that occasion Lord Armstrong was more nervous than he had ever seen him before Lord Armstrong said to him, "I never am present at the launching of a ship without wondering that such an operation is carried to a successful termination." It was a simple thing; it was a common thing; but he was not ashamed to say that he never attended a launch without feeling himself deeply moved when what had been fixed became a moving, living mass quite beyond control.

RAILWAY VIADUCTS IN CORNWALL, OLD AND NEW.

By Mr. T. H. GIBBONS, Divisional Engineer,
Great Western Railway, Plymouth.

Great Western Railway Old Viaducts in Cornwall.

The course followed by the railway from Plymouth to Truro, opened in 1859 and extended to Falmouth in 1863, traverses many cross valleys of depth too great to be economically filled up by embankments. Excluding the Royal Albert Bridge at Saltash, forty-two viaducts were placed on the 65 miles between Plymouth and Falmouth, and ten viaducts on the 26 miles between Truro and Penzance, Plate 92. The aggregate length of the forty-two viaducts was 4·8 miles, and of the ten viaducts 1·03 mile.

Without going too closely into the details of construction, which would be out of place in the general description called for on this occasion, all the above numbered viaducts may be placed under one of two classes, A or B.

Those in class A depend upon timber trusses to carry the decking and the railway, and these trusses are supported for the most part on timber piles which form the piers. This kind of construction is to be found between Devonport and St. Germans, where the railway has to cross tidal creeks, in which are deposits of mud of depths up to 70 feet. Hence followed the adoption of timber piles for foundations, carrying timber piers and trusses. 40 feet is the usual span for this class of viaduct, and the heights range between 40 and 100 feet. There are three principal viaducts of this type:—

Weston Mill, 396 yards long and 46 feet greatest height.

(This viaduct is to be replaced by a steel structure on the western side, and the works at the south end are in progress.)

Forder, 202 yards long and 67 feet greatest height.

Nottar, 378 yards long and 67 feet greatest height.

In this type of construction the changing of the timbers in any part of the main trusses involves the breaking up of the truss, which has to be cast adrift for the time, temporary support being provided to carry the decking on one side; this occupies so much time that the renewal of the principal parts of the trusses can only be done on a Sunday, when an interval of several hours between trains can be obtained. At St. Germans Viaduct, trusses of timber with wrought-iron ties and braces cover spans up to 66 feet. There is only one viaduct like this. The length is 315 yards, and the greatest height 106 feet. The piers are framed with timber, each of the four corners consists of a cluster of four baulks 12 inches square, braced horizontally and diagonally at intervals, Figs. 4 and 5, Plate 94. The renewal of timber trusses in this viaduct has to be done on a large scale; that is, all the upper work above the cills of the piers is renewed at intervals of something under twenty years. For this renewal a wrought-iron bowstring girder is used, which supports all the flooring on one side of a span, so that the timber truss can be taken away and a new one framed up to take the place of it. Twice has this operation been carried through this viaduct since the line was opened. If a new viaduct be not built within a few more years the operation will have to be repeated. The diagram elevation, Fig. 1, Plate 93, and the detail elevation and transverse section, Plate 94, show the largest example of Class A, or the trussed timber viaduct.

In Class B may be included the large majority of the viaducts, over valleys where good foundations are to be had. The general type of construction in such cases is shown on Figs. 2 and 3, Plate 93. Drawings and photos illustrating this class are also shown on Plates 95, 96, and 97. The general plan is to have masonry piers built from 60 to 66 feet apart (centres) and carried up to cill level, which is about 35 feet below level of rails. From the tops of these piers three sets of struts radiate, four struts in each set, making twelve struts on each pier; these struts are kept in place by horizontal walings and diagonal braces of timber, and on the top of the struts

are the main carrying beams in three runs for the single line; the beams are double and the top and bottom beams are united by raking bolts, joggles and keys. The top width of the viaduct is from 15 to $16\frac{1}{2}$ feet according to the construction of the parapets.

The viaducts in West Cornwall, none of which now remain, had smaller spans (50 feet centre to centre of piers) and three legs in a set instead of four, the middle one being vertical; but the main object in all these designs was to facilitate the renewal of any strut or beam without disabling the viaduct for a long time. In order to change one of the legs, less than an hour will suffice; for changing beams about double as long an occupation is needed. The general appearance of the fan-like struts and open parapets is not a disfigurement in the landscape, and several photographs given to illustrate new works show also the old ones.

The author does not intend to deal with the Royal Albert Bridge at Saltash in this general paper, but hopes that the inspection that members will make of it, will satisfy them that it is entitled to hold its own among bridges designed up to the present day. Plate 98 shows a clear view of the process of erecting one of the main tubes.

When the work now going on is finished there will remain only one timber viaduct between Truro and Penzance, namely, the low one that crosses the beach $\frac{1}{4}$ mile before reaching Penzance station.

Between Plymouth and Falmouth, speaking broadly, two-thirds of the work of reconstruction has already been done, and the work is still busily in hand. The drawings chosen to illustrate the general construction of viaducts of Class B are those of Truro on the main line, Fig. 2, and Ponsanooth on the Falmouth branch, Fig. 3; both of these, shown on Plate 93, are now carrying the traffic, and are good examples of length and height.

New Viaducts.—The first step towards reconstructing viaducts in Cornwall was taken in the year 1869 when the Probus viaduct, 145 yards long and 43 feet high, was replaced by an embankment, and the centre line of railway was improved at the same time.

Between the years 1873 and 1886 the viaducts in the Glynn Valley between Doublebois and Bodmin Road stations, eight in

number, and those near Liskeard, three in number, were dealt with, and will now be briefly described.

In 1873 a contract was let for the Drawwood deviation, which comprised the substitution of an embankment with a retaining wall, Plate 99, for Drawwood viaduct, the old viaduct being of the same type as that at Probus, while West Largin viaduct was replaced by a new viaduct with three arches in masonry, Fig. 17, Plate 101. Drawwood old viaduct was 227 yards long by 53 feet high, while West Largin was 108 yards long by 81 feet high. The stone used was taken from the company's quarry at Westwood, one mile west of Doublebois Station. This quarry furnished stone for all the eleven viaducts which are now being described.

The quarry yields a hard, durable, shale rock with flat natural beds, well suited for bridgework. Cornish granite was used for quoins of piers and arches, for impost and string courses and for coping; in some cases the Westwood quarry stone was used for dressings and for pier quoins but not for arch quoins. The mortar generally was gauged with lias lime, sand, and ashes. Proportions, 1 of lime to $1\frac{1}{2}$ or 2 of the other components. Edge stone mills were used for grinding the mortar. Following the two viaducts included in the Drawwood contract, the Cornwall Railway Company built the remaining nine viaducts with their own staff without employing a contractor, using their quarry at Westwood to supply the bulk of the stone. The extent of their operations may be estimated by a glance at the quarry, which can be seen from the railway one mile below Doublebois Station and on the down line side. Nearly all the stone taken out has been used in the reconstruction of these eleven viaducts and of two others near Grampound Road which will be described further on. The valley under Westwood viaduct and adjoining the quarry was found to be a convenient place for tipping "deads," for a great deal of the stuff excavated was not fit to use for building stone. Rubble from the quarry was also used for filling up embankments, and for building dry walls at the ends of the new viaducts. Eleven viaducts were built in this manner and in the following order:—Drawwood, Plate 99; West Largin, Fig. 17, Plate 101; Penadlake, Figs. 15 and 16, Plate 100, and Fig. 18,

Plate 101; Clinnick, Fig. 19; Westwood; Moorswater, Fig. 20, and Plates 102 and 103; Derrycombe; St. Pinnock, Fig. 25, Plate 104; Largin; Bolitho; Cartuther. Drawings are submitted of the first four; Westwood is omitted because it is very much like West Largin. It will be noticed that segmental arches not exceeding 50 feet in span are used, the heights being nowhere greater than 80 feet. In designing Moorswater viaduct, the height of the structure, 148 feet, and the width of the valley called for increased spans, and eight arches each of 80 feet span were built. In this viaduct, as in all the others, the old structure was wide enough for a single line of rails of 7 feet gauge; while the new structure was made to carry a double line of rails of 4 feet $8\frac{1}{2}$ inches gauge. In building at Moorswater, the materials were delivered by rail at the top; they were then run down an inclined plane to the pier where required, and thence lifted and set in place by one of four Scotch derrick-cranes worked by steam, which stood on stages of 70 feet in height, so that they could handle materials for the masons at a height of 120 feet above the level of the ground. These cranes were of 3 tons register, but generally the loads were not allowed to exceed 2 tons. As soon as the centres were fixed, an overhead road, at a level of 2 feet above the crowns of the main arches, with travelling cranes upon it, was used for handling materials for building arches, spandrils, and upper works. On this viaduct iron hand-rails were used for parapets with timber outside guards, one to each line of railway. The viaducts at St. Pinnock, Fig. 25, Plate 104, and Largin, of 150 feet and 130 feet in height respectively, were the first to be reconstructed on the same axis as that of the old viaducts. The original piers are of a form which allowed of their being raised so as to carry wrought-iron main girders, which were set outside the old timber structures; then cross girders and rail girders were added without removing any important carrying part of the original timber. As soon as the new girder work was completed underneath, the timber beams and struts which were no longer wanted to support the railway were taken out piece by piece; and lastly the timber decking planks were removed a few at a time, and their places

taken by Barlow rails. By this operation all perishable material was removed from the viaduct, and it was effected without any interruption of the traffic on the single line overhead. This line remained single for about ten years, and ran along the axis of the viaduct; but when the line was doubled in 1898 the up and down roads were each placed on the side belonging to them. The line of division between the new and the old masonry of the piers is more clearly marked in the photograph, Fig. 25, than in the work itself at the present time, after the new work has been exposed to the weather in the Glynn Valley for nearly twenty years.

The remaining three viaducts — Derrycombe, Bolitho and Cartuther—were re-built with masonry arches of segmental form, span being $56\frac{1}{2}$ feet and the rise 20 feet.

Derrycombe has four arches with a central height of 78 feet.

Bolitho has seven arches with a central height of 115 feet.

Cartuther has five arches with a central height of 90 feet.

Bolitho viaduct had to be built without the purchase of any additional land. The piers were completely built up to the level of impost course, as they did not come opposite the old ones; then the arches were built in two parts longitudinally; the first part was just wide enough to carry one line of rails to the 7 feet gauge; as soon as the traffic had been turned upon the new work, the old viaduct was taken down and the missing width was added to the arches from end to end of the new viaduct, so as to provide for double line of 4 ft. $8\frac{1}{2}$ ins. gauge. By due allowance in erecting and loading the centres any crack or inequality in the line of junction of the two parts of the arches was avoided. The eleven viaducts in this section of the line having been completed, two were built between Burngullow and Grampound Road Stations. The arches have the same dimensions as those of the four viaducts last described.

Fal viaduct has seven arches with a central height of 90 feet.

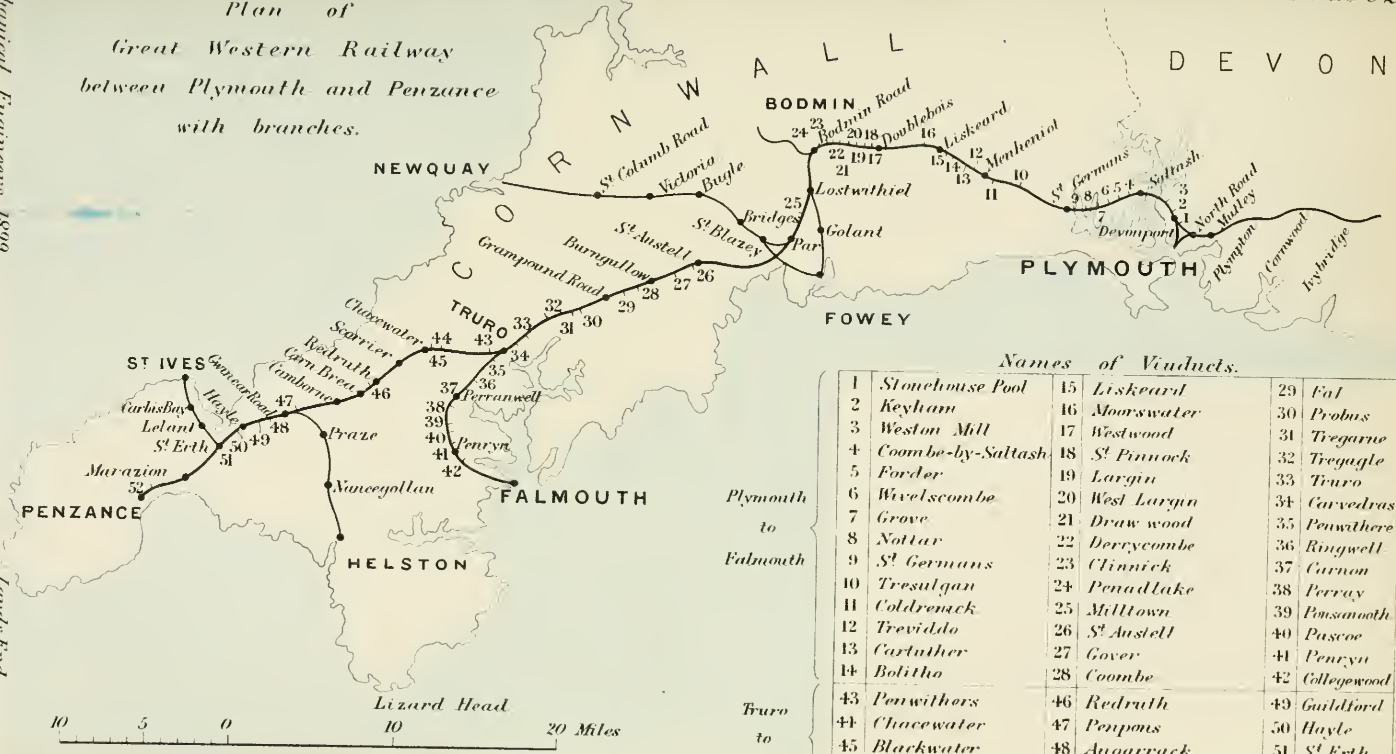
Coombe (St. Stephen's), Fig. 27, Plate 105, has ten arches with a central height of 70 feet.

These viaducts call for no special description, being similar to those that have gone before in this paper. Coombe viaduct is an example of arches of $56\frac{1}{2}$ feet span. This was the farthest point

Plate 92

RAILWAY VIADUCTS.

Plan of
Great Western Railway
between Plymouth and Penzance
with branches.

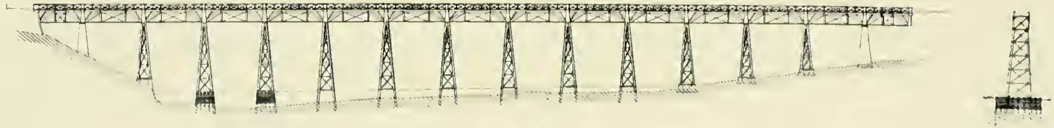


Names of Viaducts.

	No.	Name	No.	Name	No.	Name
Plymouth to Falmouth	1	Stonehouse Pool	15	Liskeard	29	Fal
	2	Keyham	16	Moorswater	30	Probus
	3	Weston Mill	17	Westwood	31	Tregarne
	4	Coombe-by-Saltash	18	St Pinnock	32	Tregagle
	5	Forder	19	Largin	33	Truro
	6	Wivelscombe	20	West Largin	34	Carvedras
	7	Grove	21	Draw wood	35	Penwithers
	8	Nottar	22	Derrycombe	36	Ringwell
	9	St Germans	23	Clinnick	37	Carnon
	10	Tresulgan	24	Penadlake	38	Perray
	11	Coldrenick	25	Milltown	39	Ponsanooth
	12	Treviddo	26	St Austell	40	Pascoe
	13	Cartuther	27	Gover	41	Penryn
	14	Bolitho	28	Coombe	42	Collegewood
Truro to Penzance	43	Penwithers	46	Redruth	49	Guildford
	44	Chacewater	47	Penpons	50	Hayle
	45	Blackwater	48	Angarrack	51	St Erth
					52	Penzance

RAILWAY VIADUCTS.

Fig. 1. *St. Germans Viaduct. Class A.*



See Details Plate 91.

Fig. 2. *Truro Viaduct on the Main Line. Class B.*

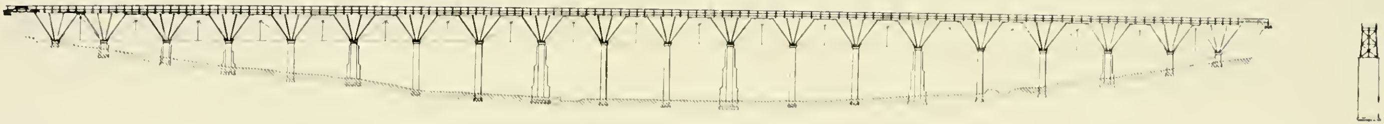
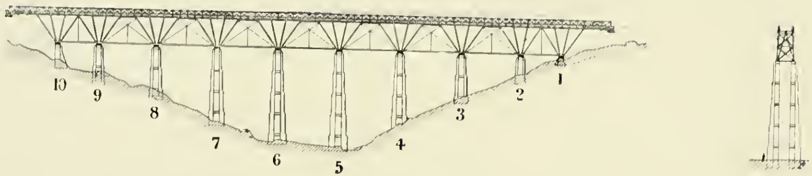


Fig. 3. *Ponsanooth Viaduct on the Falmouth Branch. Class B.*



See Details Plate 95.

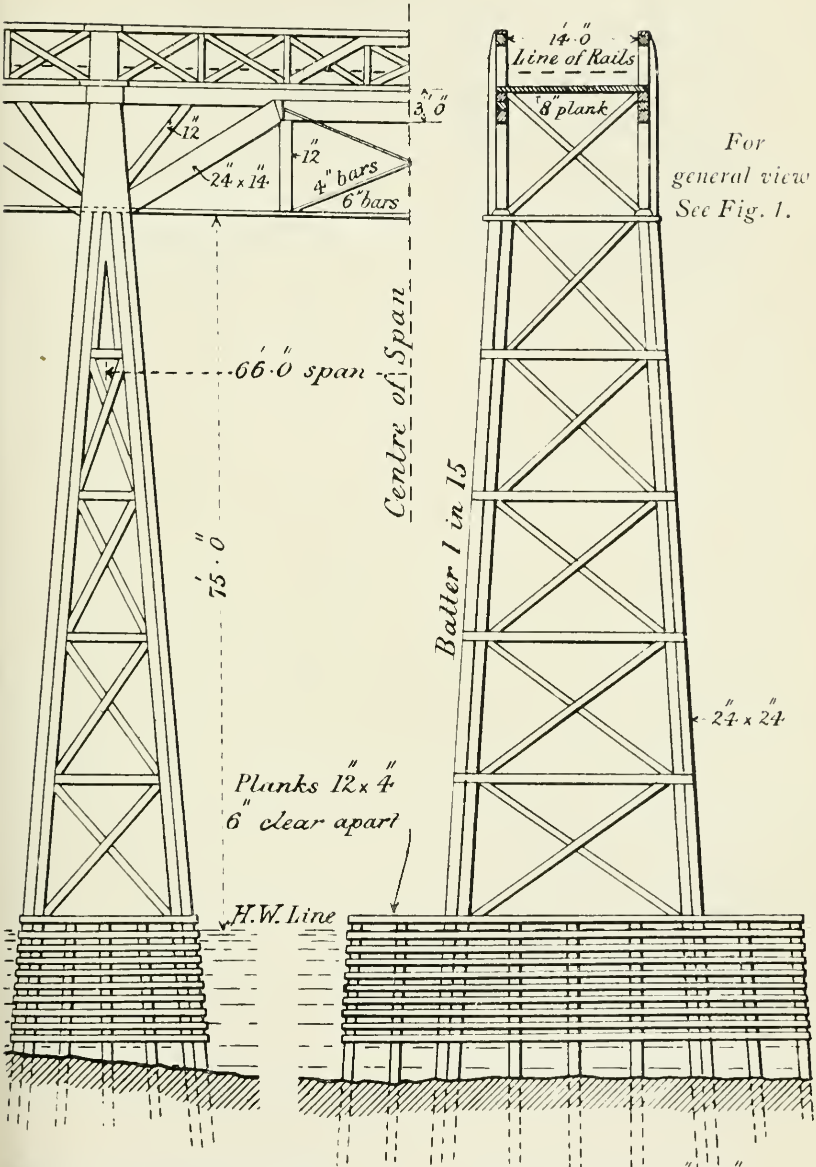
Mechanical Engineers 1899.

100 0 100 200 300 400 500 600 700 800 900 Feet.

Plate 93.

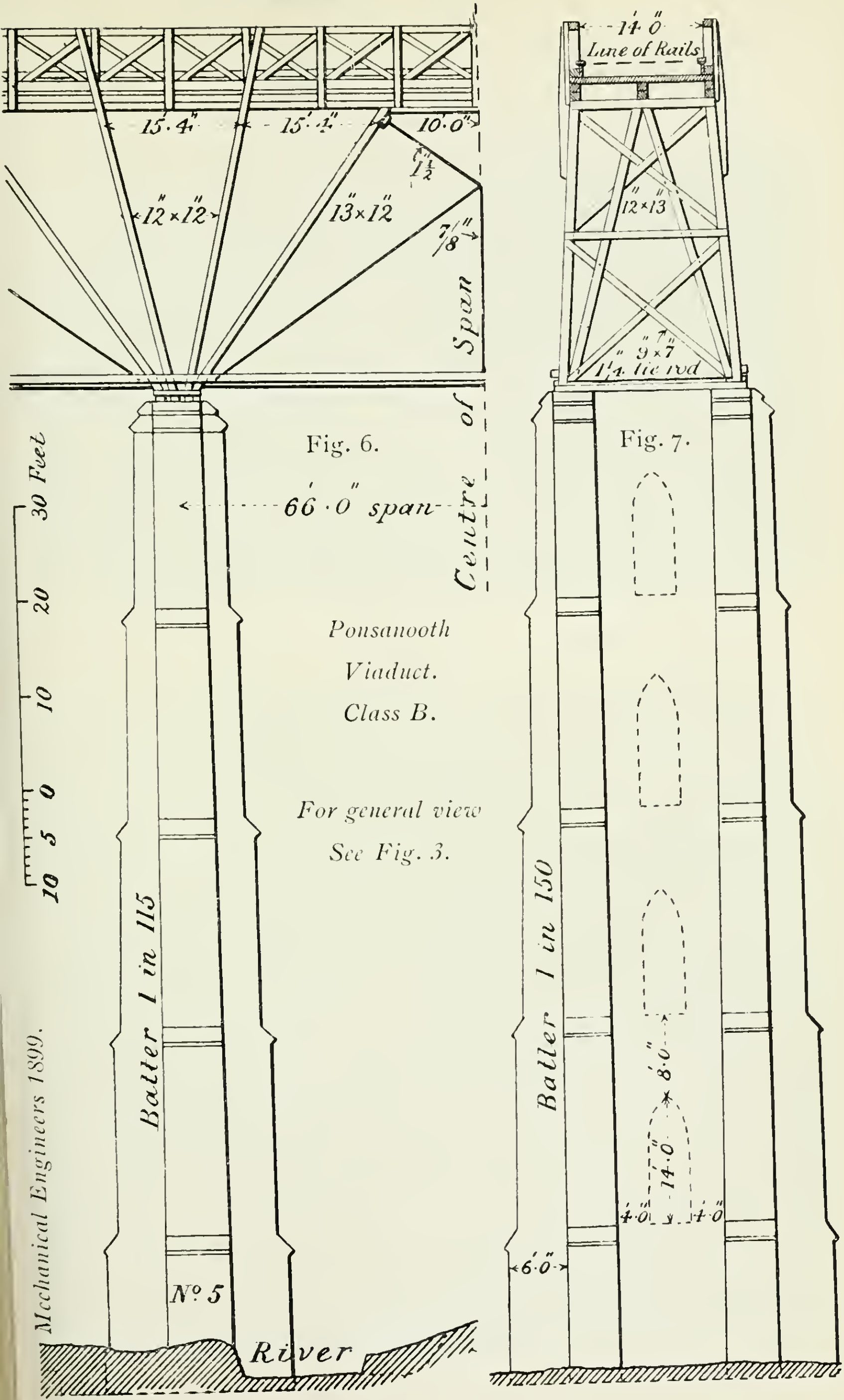
St. Germans Viaduct, still in use.

Fig. 4. *Class A.* Fig. 5.



Mechanical Engineers 1899. *Memel Piles 22″ x 22″*

Feet 10 5 0 10 20 30 40 50 60 Feet


14' 0"
Line of Rails
15' 4"
15' 4"
10' 0"
1½"
12" × 12"
13" × 12"
⅞"
12" × 13"
9" × 7"
1¼ tie rod
Centre of Span
Fig. 6.
Fig. 7.
66' 0" span
30 Feet
20
10
0
5
10
Ponsanooth
Viaduct.
Class B.
For general view
See Fig. 3.
Batter 1 in 115
Batter 1 in 150
8' 0"
14' 0"
4' 0"
4' 0"
6' 0"
No. 5
River

St. Austell Viaduct. Class B.

Fig. 8. *Now taken down.*

Fig. 9. *New Work in progress.*

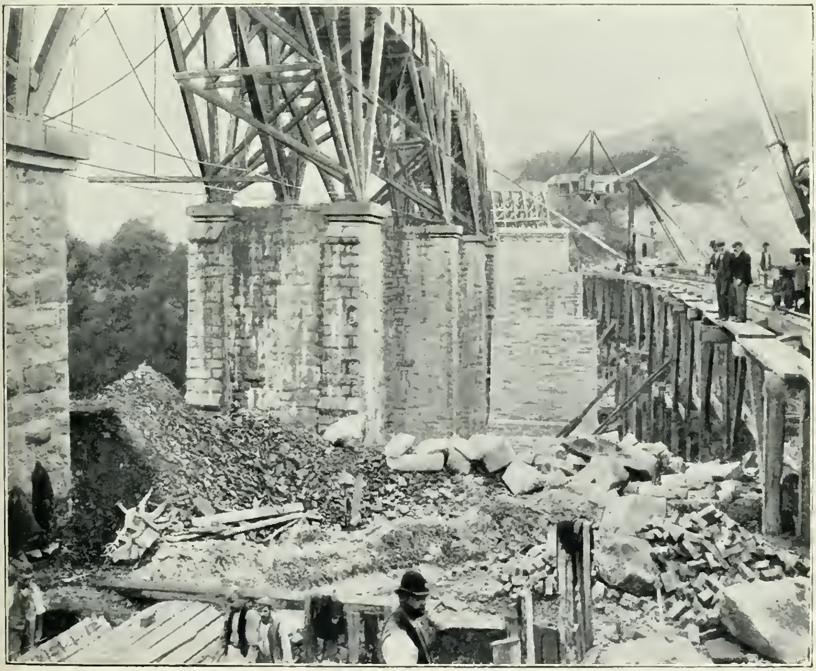


Fig. 10. *Gover Viaduct, now removed. Class B.*

233 yards long. 95 feet central height.

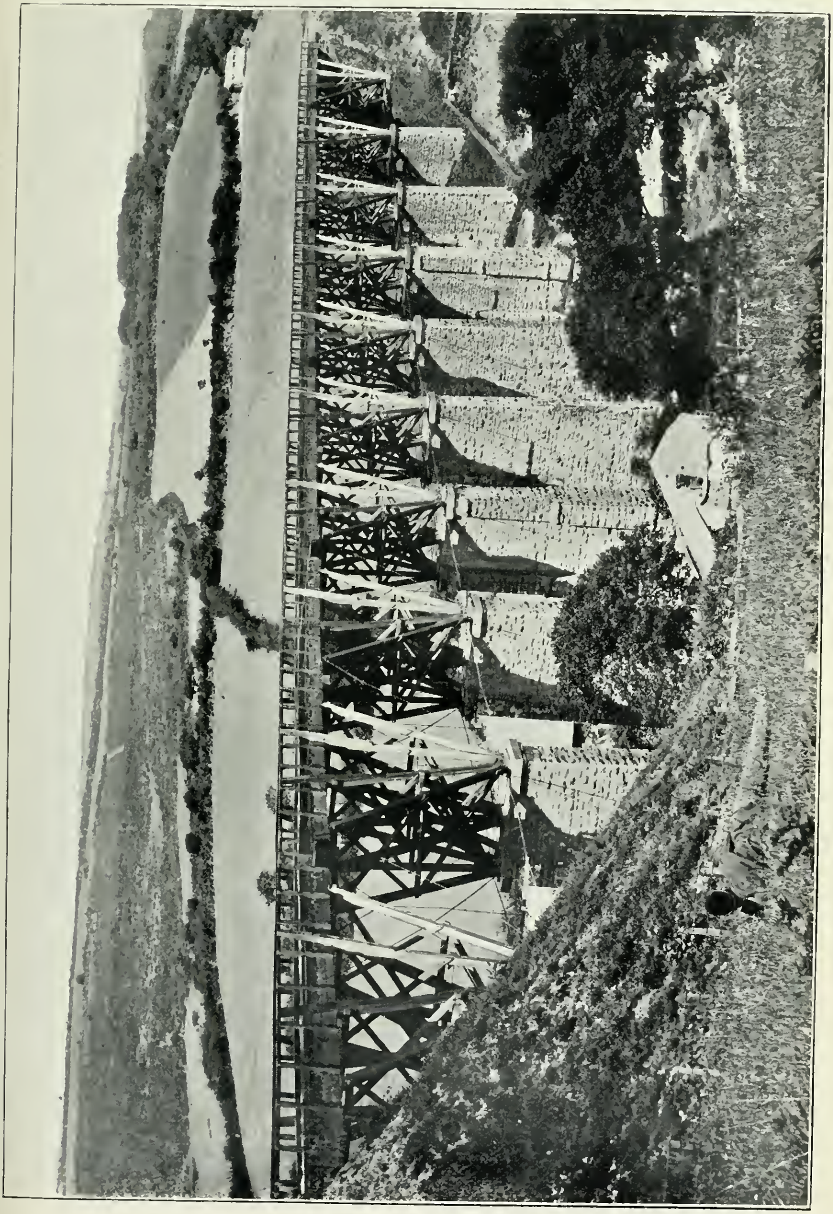
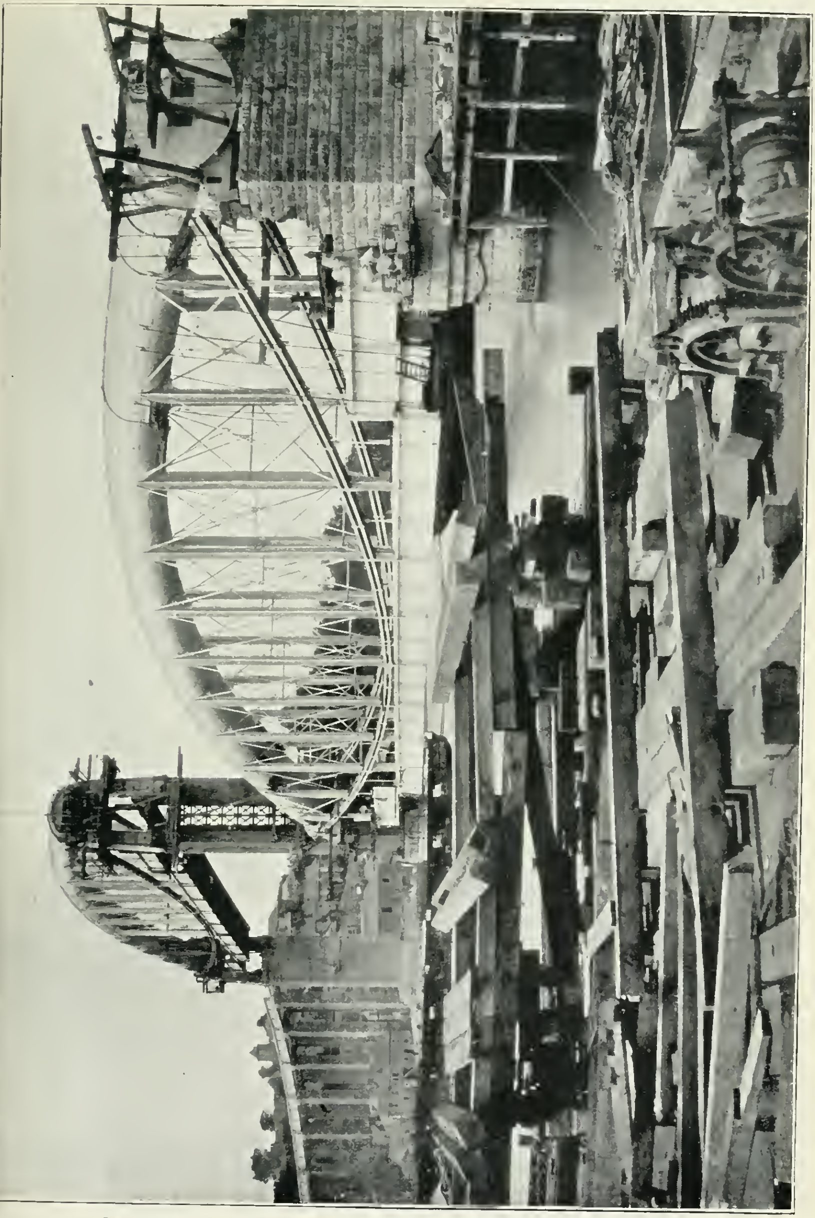
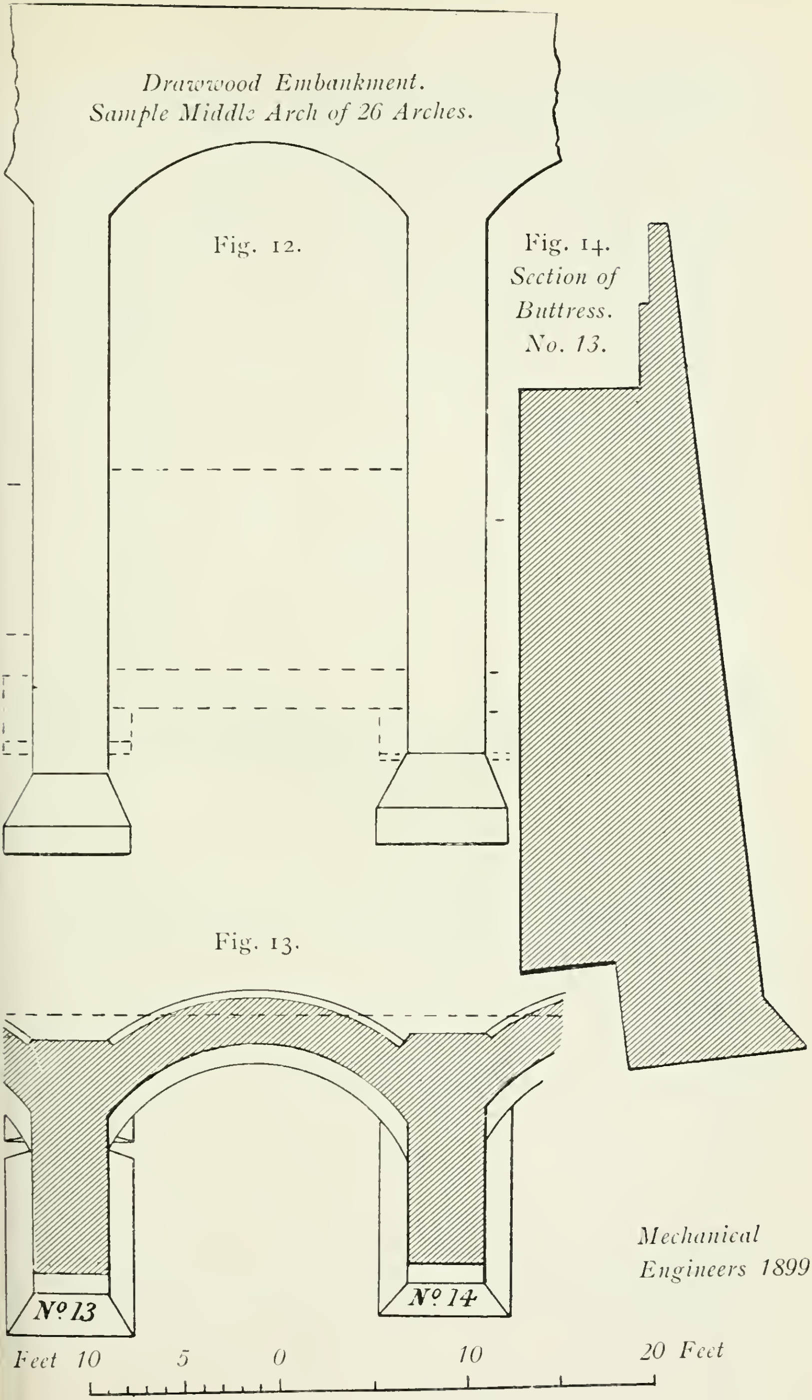


Fig. 11. *Royal Albert Bridge at Saltash. Opened 1859.*
Erecting one of the Main Tubes.



Oval tubes 17 feet × 12 feet. Arches 445 feet wide.
Height 100 feet above high water. Length nearly half-a-mile.

Mechanical Engineers 1899.



Mechanical Engineers 1899.

Penadlake Viaduct.

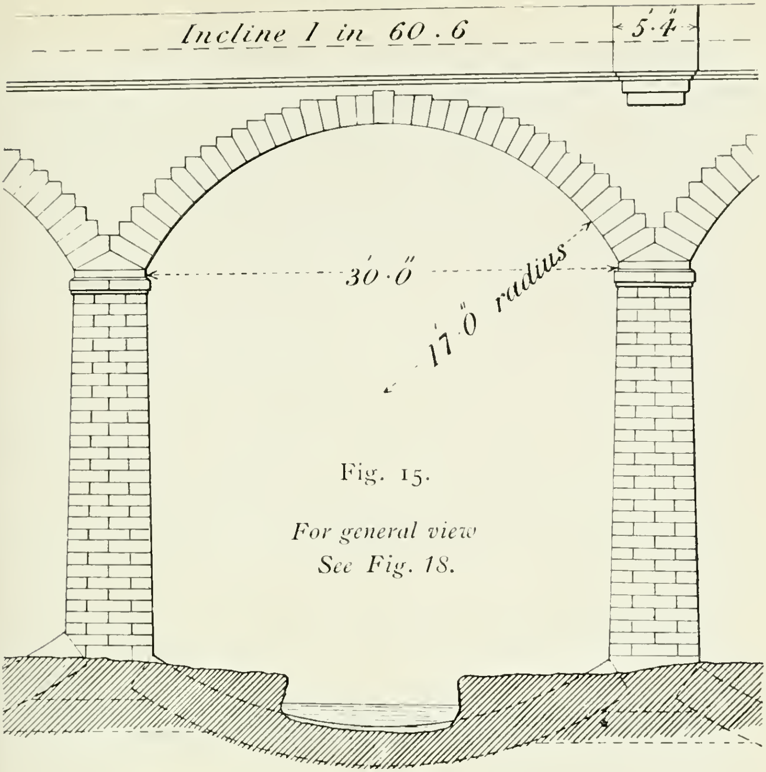


Fig. 15.

Fig. 16.

Mechanical Engineers 1899.

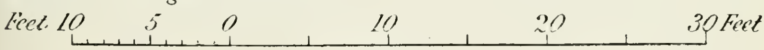
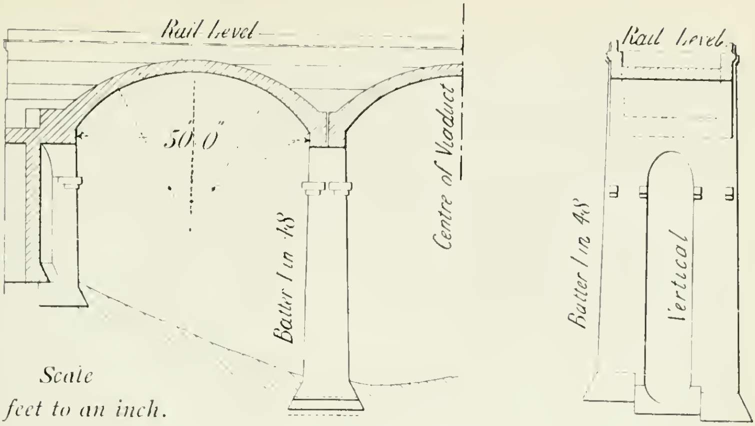
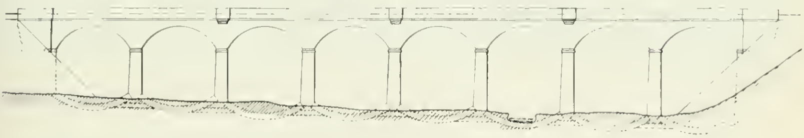


Fig. 17. *West Largin Viaduct. Three Arches.*



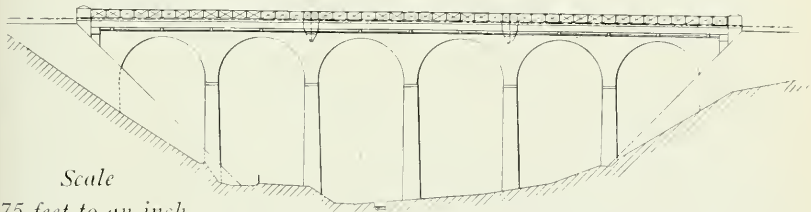
Scale
10 feet to an inch.

Fig. 18. *Penadlake Viaduct.*
See Details, Figs. 15 and 16. Plate 100.



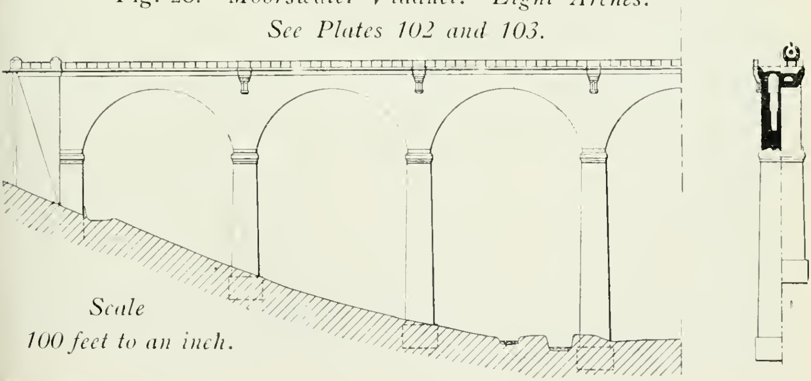
Scale 75 feet to an inch.

Fig. 19. *Clinnick Viaduct.*



Scale
75 feet to an inch.

Fig. 20. *Moorswater Viaduct. Eight Arches.*
See Plates 102 and 103.



Scale
100 feet to an inch.

Moorswater Viaduct. April, 1879.

Fig. 21.

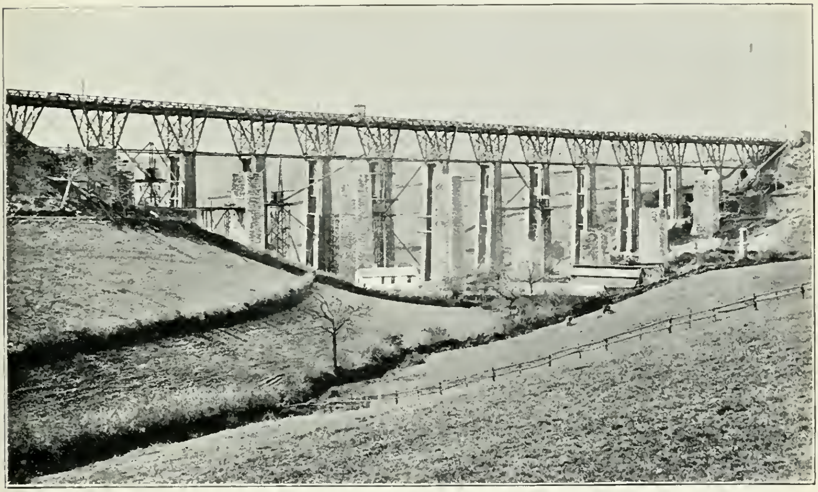
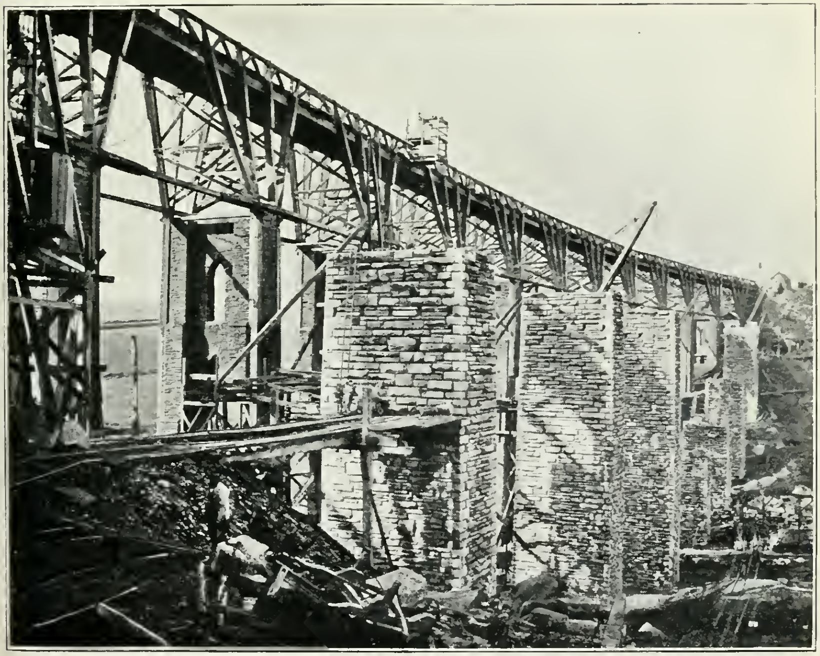


Fig. 22.



Moorswater Viaduct.

Fig. 23. *June 1880.*

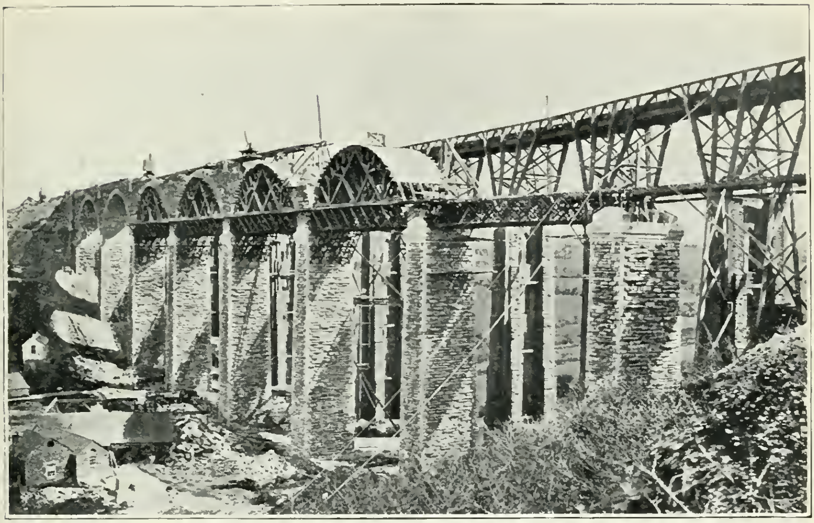


Fig. 24.

Fig. 25. *St. Pinnock Viaduct, completed 1886.*

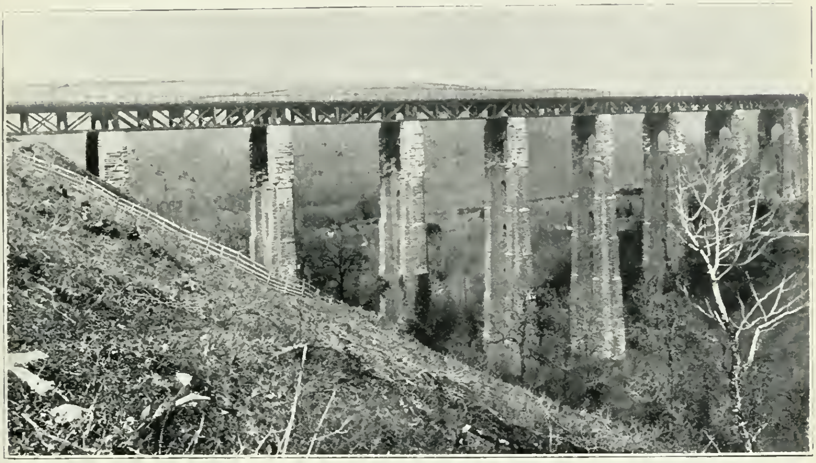


Fig. 26. *Angarrack Viaduct, completed 1885.*

RAILWAY VIADUCTS.

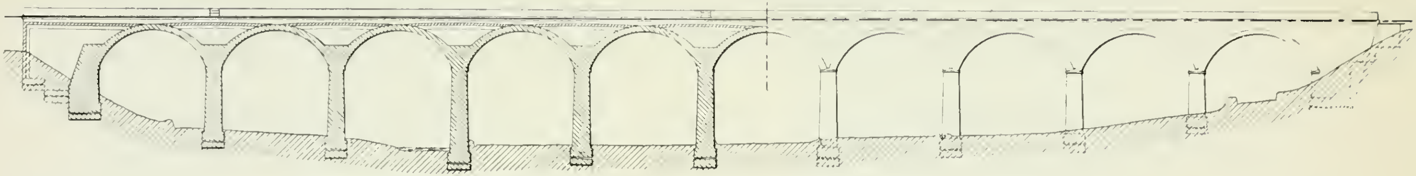


Fig. 27. *Coombe (St. Stephen's) Viaduct.*

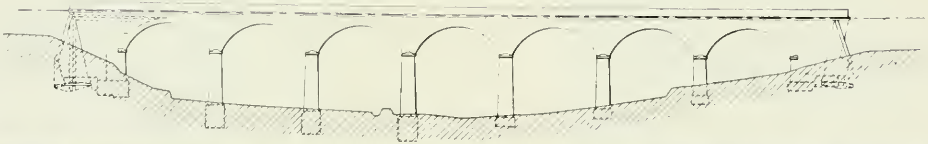


Fig. 28. *Penwithers Viaduct.*

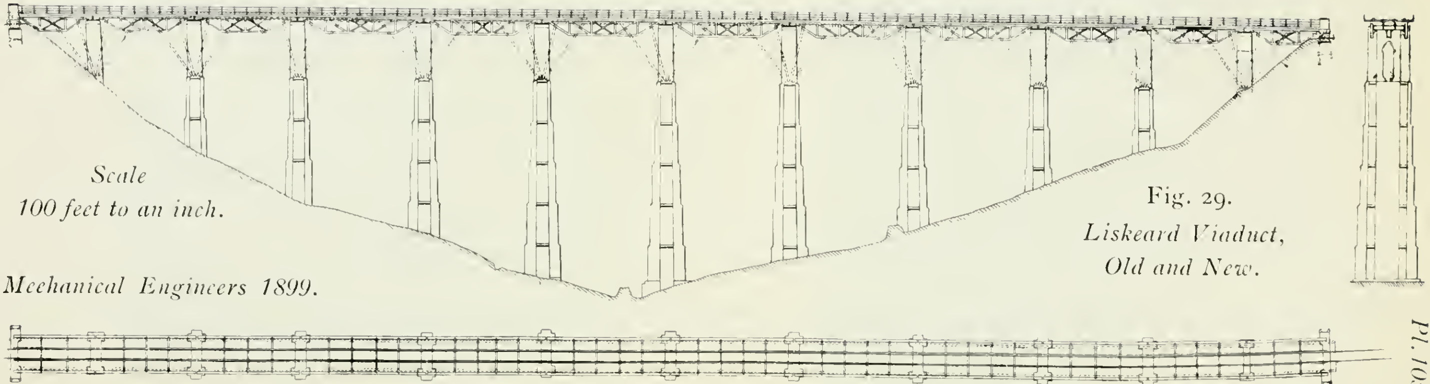


Fig. 29. *Liskeard Viaduct, Old and New.*

Scale 100 feet to an inch.

Mechanical Engineers 1899.

Coombe-by-Saltash Viaduct.

Fig. 30. *New Works in progress.*

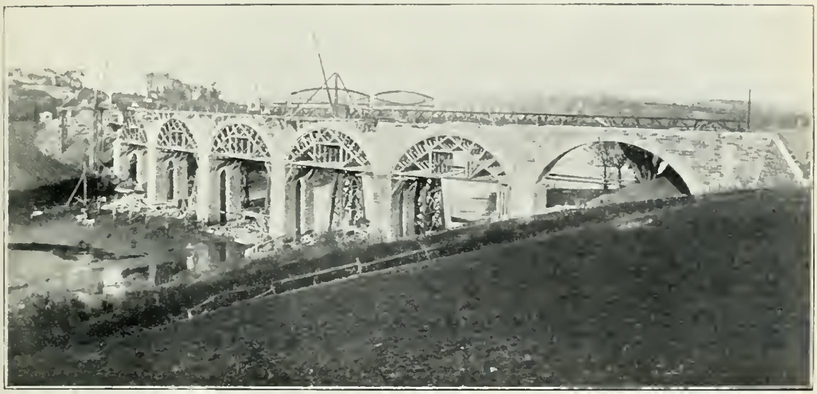


Fig. 31. *Arches 70 feet span, 25 feet rise.*

RAILWAY VIADUCTS.

Fig. 32. *Coombe-by-Saltash Viaduct, showing old and new structures.*

Plate 107.

Keyham Viaduct, 19th February, 1899.

Showing old stone and new brick extension of piers, old wooden trusses, and new iron girders.

Fig. 33. *Iron Girder slung.*

Fig. 34. *Girder fixed.*

westward to which the stone from the quarry near Doublebois was carried.

The last viaduct ordered by the Cornwall Railway Company was Coombe-by-Saltash, Plates 106 and 107. It was built by contract, the contract being signed in 1889, after the line had been taken over by the Great Western Railway Company. It is situated close to the Saltash station, and carries the railway across a tidal creek where mud to a depth of about 45 feet is found. The foundations being costly, a span of 70 feet was adopted for the arches, which are seven in number, while the central height is 86 feet above the surface of the mud. Timber cofferdams were used for the three piers in the tidal estuary, and a good rock foundation was obtained throughout.

Between the years 1883 and 1889 the Great Western Railway Co., who owned the West Cornwall line between Truro and Penzance, reconstructed seven viaducts on that section of their system. Between Truro and Chacewater stations three were built with granite masonry, with arches of 45 feet span and 15 feet rise. Penwithers, Fig. 28, Plate 105, has seven arches with a central height of 68 feet; Chacewater has five arches with a central height of 55 feet; Blackwater has seven arches with a central height of 70 feet. The drawing of Penwithers will suffice to illustrate all the viaducts of this class.

Redruth viaduct, close to the station of that name, is also built with granite masonry, and has seven arches of 56½ feet span and rise of 20 feet; and one of 60 feet span over Penryn Street. This viaduct was built in two sections throughout, for here as at Bolitho lack of land required the site of the old viaduct to be ultimately occupied by the new work. Piers as well as arches were put up at two operations, and without any perceptible indications remaining to show the line of junction.

Angarrack viaduct, between Gwinear Road and Hayle stations, is also of granite; it has eleven arches of 56½ feet span with a rise of 20 feet, and it crosses a broad valley at a height of about 100 feet. A photograph, Fig. 26, Plate 104, of this viaduct shows it when nearly completed. Half a mile nearer Hayle, Guildford viaduct will be found. It has arches of the smaller size, 45 feet with a rise

of 15 feet. They are six in number, with a central height of 53 feet. The drawing of Penwithers, Fig. 28, Plate 105, suffices to illustrate this type of work. All these were built by contract.

Adjoining Hayle Station is a long low viaduct with thirty-six spans of about 20 feet each, and two spans of 40 feet. In reconstruction the axis of the old viaduct was retained; new piers were built and old ones enlarged; and the timber superstructure was replaced bit by bit with one of wrought iron. The erection of the new superstructure was done by the Company's staff, while the rest of the work was let by contract.

Following the amalgamation of the Cornwall with the Great Western Railway Company, the narrowing of gauge works ensued in 1892, and soon afterwards the work of viaduct reconstruction in Cornwall, in connection with the doubling of certain sections of the line, was undertaken on a large scale. The general lines of the earlier reconstruction were not changed—that is to say, where the height of the old viaducts and the piers admitted it, new steel superstructures were erected on the original piers, which were raised for the purpose. Examples of this are to be seen at Liskeard viaduct, close to the station; at Coldrenick viaduct close to Menheniot station. The method of erection on the original axis and without interruption of traffic was the same as has been described in the case of St. Pinnock and of Largin viaducts; but instead of the Barlow rail decking formerly used, corrugated steel flooring is applied; and the piers are raised with Staffordshire bricks instead of with stone masonry. Liskeard viaduct is illustrated by Fig. 29, Plate 105, which shows old and new work.

At Keyham viaduct, Plate 108, near Devonport station, the process of reconstructing in steel on the old piers raised is now in progress. Here it has been necessary to widen some of the piers from the foundations; in the former instances the new masonry or brickwork begins at about 35 feet below level of rails. The form of the old piers at Keyham is not so suitable as in those at Liskeard and elsewhere. In all these viaducts erected on same site as that of the running lines, the girder work is provided by contract, but all the rest is done by the company's staff.

New viaducts in granite masonry, with arches differing but little from those already described, have been built at Treviddo and Tresulgan, one on each side of Menheniot station; these have only been lately opened for traffic, and at Tresulgan the old viaduct has not yet been removed. At Milltown, near Lostwithiel, a viaduct like that at Treviddo was completed in 1895. Two large viaducts of similar character have recently been completed near St. Austell. Gover viaduct has eight arches with a central height of 99 feet. St. Austell viaduct, Fig. 9, Plate 96, has ten arches with a central height of 115 feet.

Arched viaducts in granite masonry not yet completed or open for traffic are situated thus:—Tregarne, between Grampound Road and Truro; Tregagle, between Grampound and Truro; Penponds, one mile below Camborne station. All these masonry viaducts are being built by contract; they have the main arches turned with Staffordshire bricks, and the parapet walls, and in some cases the spandril walls, are also of the same material. Plates 103 and 106 illustrate the type of design adopted in these of current date. The foundation generally obtained throughout the series has been shale rock, the beds being inclined at various angles, between the horizontal and vertical; and no single case of settlement due to failure in a foundation to carry its load has arisen, from the beginning of the reconstruction work up to the present time. From ten to fifteen feet of excavation has generally sufficed to reach the rock; in a few cases the depth has been twice as great. Timber centering has been used, several viaducts in succession being served by the same centres. American yellow pine is the timber used generally in the Cornwall viaducts, and the preserving process is that known as kyanizing. This process has been found to render the timber not liable to catch fire easily, and this is a very necessary qualification in preparing timber for such purpose and situation.

Discussion.

The PRESIDENT asked the members to accord a vote of thanks to Mr. Gibbons for his kindness in preparing the very interesting account of works of great variety, involving very large responsibility, which he believed, had fallen upon the author. By the invitation of Mr. Gibbons and the Great Western Railway Company, members who wished to do so would be able to see some of the representative viaducts and bridges described in the Paper. He remembered the floating of the first section of the Royal Albert Bridge. In their ignorance they were accustomed to think that the free use of timber on the viaducts in Cornwall had some connection with the necessarily great cost of the Albert Bridge; but whatever might be true in that respect there was no doubt that those who had to undertake the maintenance and development of the Cornish lines were now putting upon them work of an entirely different character from that which had been originally done.

Mr. GIBBONS said he had nothing particular to add to the substance of his Paper, and thanked the members for the cordial way in which the President's kind remarks had been received. He had a considerable number of photographs which he would lay on the table if any gentleman would like to look at them, because they illustrated the more recent construction that had been going on. A glance at the photographs of the works would speak a great deal more clearly to members, whose time was short and who had only a limited opportunity of looking over the great area covered by the works, than any remarks he could make. Any gentlemen who were able to go to the Royal Albert Bridge or to the Western Mill viaducts would be heartily welcomed by members of the Great Western Railway staff.

THE MECHANICAL APPLIANCES EMPLOYED IN THE CONSTRUCTION OF THE KEYHAM DOCKYARD EXTENSION WORKS.

By Mr. WHATELY ELIOT,
Admiralty Superintending Civil Engineer,
Keyham Extension Works.

The great advances that have been made in machinery of every description during the latter part of this century have had a great effect upon all kinds of public works, both in reducing their cost and also in limiting the time required for their execution. For instance, such a work as the Manchester Ship Canal would probably never have been attempted, if the steam navvy had not come into existence to take the place of the pick and shovel. The time that would have been occupied in excavating and removing the millions of yards of material in the various cuttings of the canal would have amounted to many years of pick and shovel work, instead of the marvellously short time that was actually required by the use of the steam navvy. As in excavation so in other work, the old methods are being superseded by the various ingenious machines that are being constantly devised, thus enabling those engaged in large public works to view with complacency figures representing such enormous quantities of work as would have almost appalled them in former days. It is apparent that the cost of many operations connected with the carrying out of large works has been considerably lessened by machinery, from the readiness with which contractors adopt the same wherever practicable. These remarks of course apply to large works, where the quantities to be dealt with are of such a nature and amount as to bear the cost of providing the requisite machinery.

The work now being carried out in the extension of the dockyard at Keyham appears to afford a good example of the use of machinery in all available situations.

These works, Plate 109, occupy ground to the extent of 113 acres, of which 35 acres are situated above high-water mark, being chiefly land which has been reclaimed in former years from that part of the Tamar called the Hamoaze. The remainder of the area, 78 acres in extent, is the foreshore of mud from high-water line to about low water of spring tides, the range of tide being 15½ feet. The works comprise a tidal basin of 10 acres and a closed basin of 35½ acres, divided by a space about 900 feet in width, in which space there will be three large graving-docks as shown on the plan. Two of these graving docks will have an opening at either end, and will be accessible from either basin. There will also be a lock leading from the closed basin to outside the tidal basin: this lock will be constructed to be used as a graving dock if required. Extending along the whole length of the works, and facing the Hamoaze, will be an outer quay wall with sufficient depth of water for the largest class of battleships at any state of the tide. The whole of the river front of the site is enclosed during construction by a cofferdam, to exclude the tidal and river water: this cofferdam is more than a mile in length.

From the magnitude of the works, it will be at once seen that a very large amount of machinery must be employed to complete them in a reasonable time. It is therefore proposed to describe briefly the machinery which is here being employed with advantage in excavation, dealing with materials, building operations, and workshops. The whole work is being carried out by contract, Messrs. Sir John Jackson, of Westminster, being the contractors.

Excavation.—There are three different materials to be dealt with in the excavation, namely, made ground, mud, and rock.

Made ground consists of rubble which was obtained from the rock excavated in the construction of the existing Keyham docks and basins, and was tipped on the mud foreshore some thirty years ago, to reclaim land north of the Keyham yard. The depth of this rubble

Fig. 1. *Keyham Dockyard Extension.*

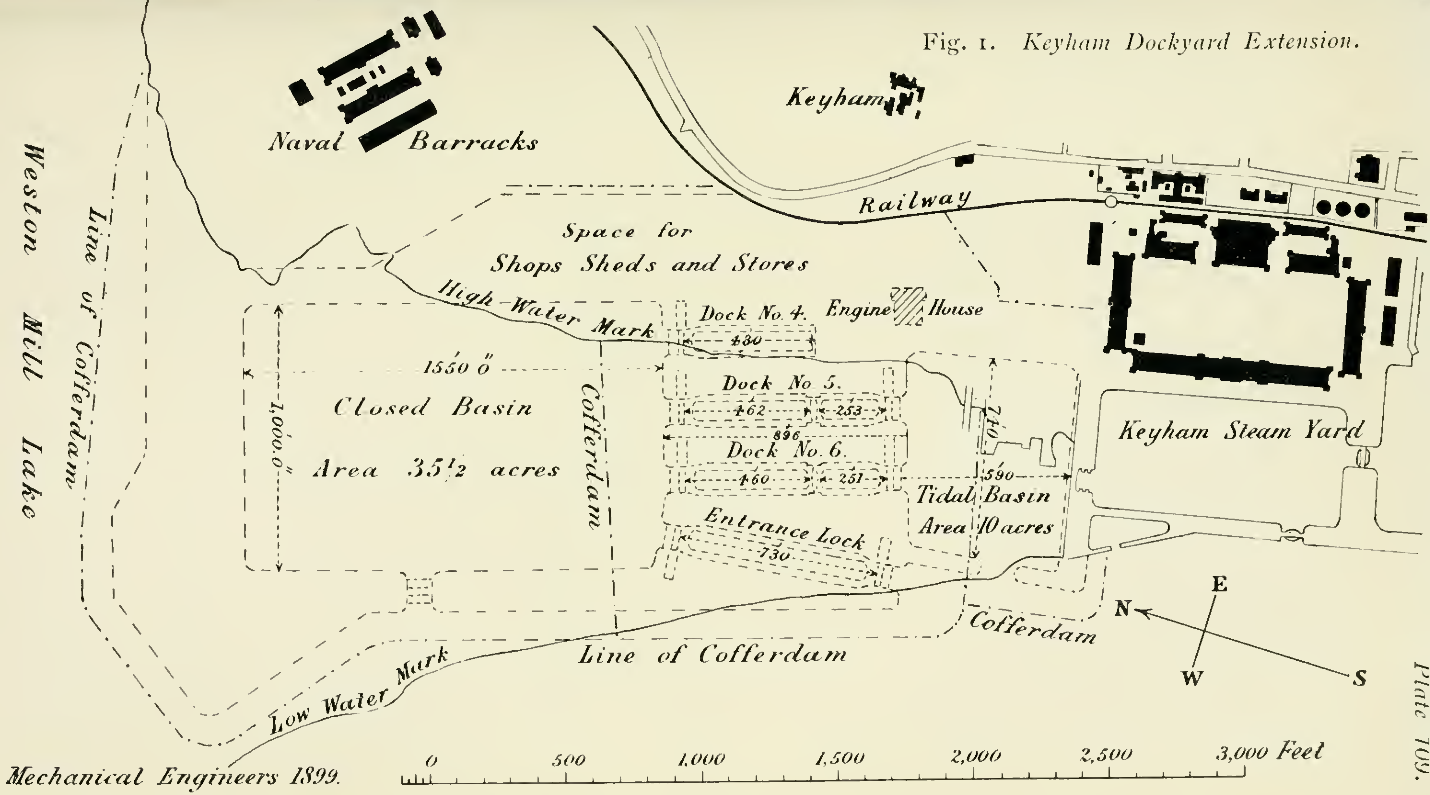


Plate 109.

Mud Scoop.

Fig. 2. "*Cutting.*"

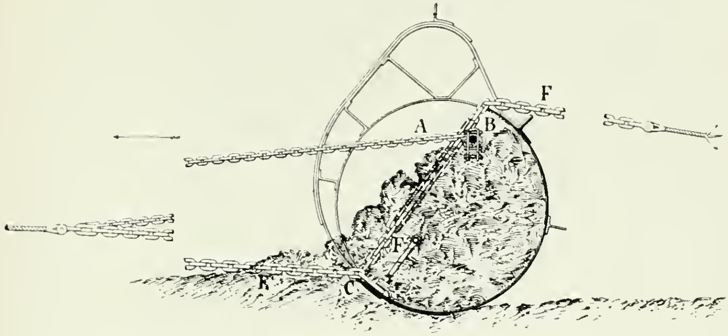


Fig. 3. "*When full.*"

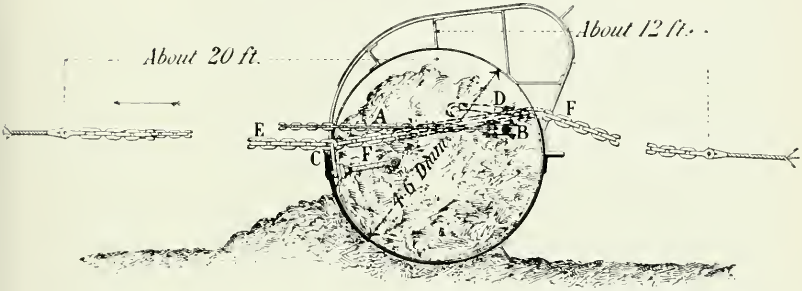
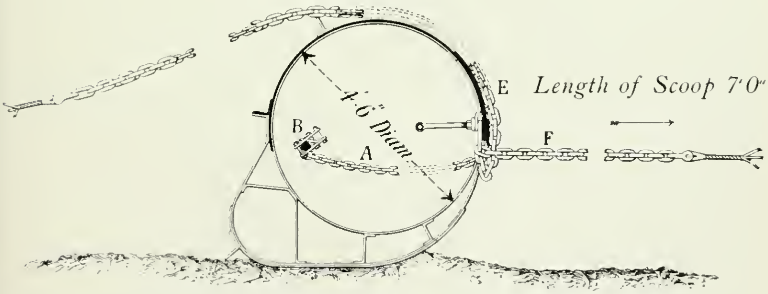


Fig. 4. "*Returning Empty.*"



0 3 6 9 12 *Feet.*

CONSTRUCTIONAL MACHINERY AT KEYHAM DOCKYARD.

Fig. 5. *Excavation of Mud on site of Docks.*

Plate 111.

Revolving Concrete Mixer.

Fig. 6.

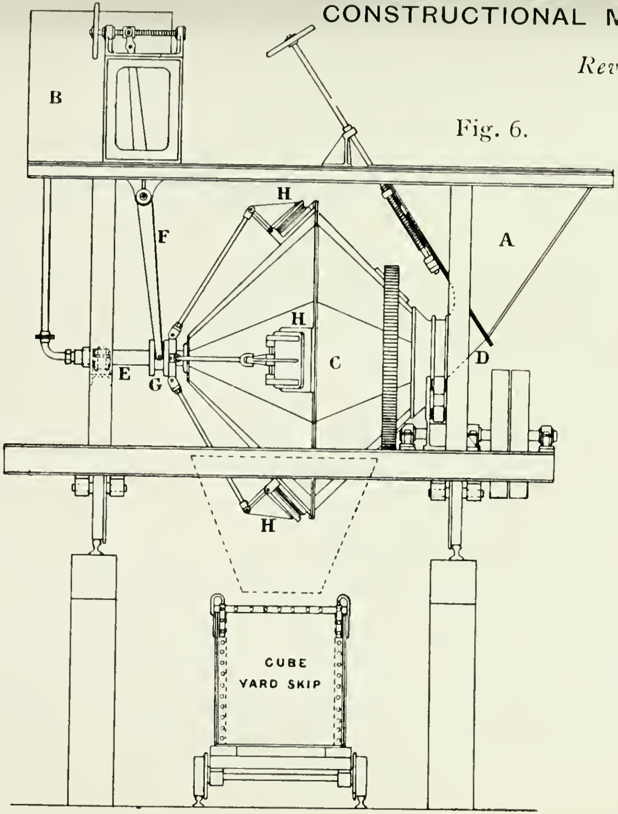


Fig. 7.
End view showing
Bearing for Trunnion.

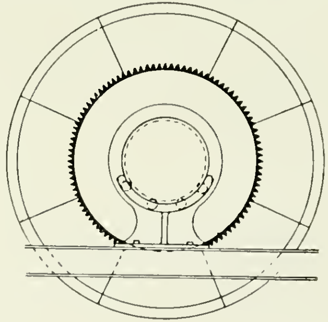


Plate 112.

averages about 20 feet. A part of this has been taken out in trenches for those portions of the walls of the basins and docks, which are situated landwards of the original high-water mark. The material was excavated by hand-labour, filled into skips, and lifted out of the trenches by steam cranes, the contents being tipped into wagons, which were conveyed by locomotives to suitable parts of the works. The remainder of the material, forming the made ground which has to be removed, being distributed over a large area to an average depth of 12 feet, will be ultimately excavated by some of Ruston and Proctor's steam navvies, and removed to be made use of where required. The appliances for this work are steam navvies, 5-ton steam cranes, iron skips, etc. Locomotives are employed in removing all excavated and other materials to and from such parts of the works as may be desired.

The mud is of two qualities, hard and soft; the hard is that on which rubble has been tipped in former years, and which has become compressed to such an extent that it is now quite dry and hard, and of the nature of stiff clay. Being under the made ground it is met with only in the deep trenches which are situated landwards of the high-water line. It is excavated and dealt with in the same manner as the made ground. The soft mud is that which has remained uncovered and exposed to the action of the tide, being the foreshore between high and low-water marks, and extending from the surface down to the rock. It lies consequently on the site of the graving docks and the basins. This mud, of which there is a very large quantity to remove, is excavated at first by means of mud scoops, Plates 110 and 111, worked to and fro over the site by hauling engines which are placed on each side of the ground. Those on the outside are of 40 H.P. and are fixed at the end of an elevated stage, from which the mud is discharged into barges and conveyed by them to sea; those on the inside are of 20 H.P. and are fixed to travelling-frames, and can thus be moved to lead the scoop to such part of the mud as may be required. The mud scoop, Plate 110, on being hauled forward over the mud, fills itself, the depth to which the cutting edge enters the mud being regulated by the tilt given to the scoop by the arrangement of the hauling chains. These chains are attached

to the front and the back of the scoop—those on the back A can be shortened by winding round the bar B to which they are attached; this shortening of the back chains causes the scoop to tilt forward and the cutting edge C to enter the mud, as in position Fig. 2. When the scoop is filled, a catch D, holding the rod on which the back chain is coiled, is knocked out; the back chain is at once lengthened, and the cutting edge is lifted by the front chain E, and the scoop takes position Fig. 3. It is in this position hauled over the surface of the mud, up an incline and along the high-level stage until it is over the shoot leading to the barge beneath. The rope F of the hauling engine on land is so arranged that, as soon as it begins to haul the scoop back, the latter is caused to turn completely over, and thus discharge its contents through an aperture in the staging, and down a shoot into the barge. The empty scoop is now in position Fig. 4, and is drawn in this position back down the incline and across the surface of the mud to fill itself again as soon as the forward hauling engine turns it over into position Fig. 2. The back chain is set to the proper length as soon as the scoop is empty, and before it commences the return journey. One complete journey is made in from 5 to 10 minutes, the load varying from 2 to 3 cubic yards when the mud is very wet to a maximum of about 5 cubic yards when it is dry. The wear and tear on the wire hauling-ropes is very great, and it is found difficult to control the work of the scoops. They however answer their purpose in preparing the way for wagons, which could not have been used at first upon the soft mud during the wet winter months. Wagons have now almost entirely replaced the scoops; these are filled partly by hand and partly by steam navvies, the latter being used as soon as the site is sufficiently opened up to allow of the necessary roads being laid down to take away the mud as excavated. Small locomotives are used in hauling the wagons, as filled from the steam navvies, to the foot of the inclines, and for supplying the navvies with empty wagons. The wagons are drawn up the inclines by the hauling engines which have previously worked the scoops. The walls of the basins are constructed in timbered trenches, and the soft mud in these trenches is excavated by hand and filled into skips, which are lifted

out of the trenches by steam cranes, discharged into wagons, and conveyed by them to the barges. Six large hopper-barges are employed in conveying the mud to sea, two being steam barges, while two powerful tugs are employed in towing the others. The special appliances for dealing with the mud are mud scoops, hauling engines, steam navvies, locomotives, skips, wagons, etc.

The rock is of a slaty nature, is much decomposed on the surface, which portions are not generally hard to excavate. In the trenches the rock is drilled by hand for blasting, and also by rock drills worked by compressed air. When loosened by blasting, the rock is excavated by hand and filled into skips and treated in the same way as the other material nearer the surface. On the site of the docks and basins, when the rock has been loosened by blasting, it will be excavated as much as possible by steam navvies. The special appliances for the rock are air-compressors, rock drills, steam navvies, steam cranes, etc.

Dealing with Materials.—On a work of this nature, where the various materials which are required are delivered in very large quantities, it is necessary that extensive arrangements be made for landing, removing, and storing them expeditiously as they arrive. Nearly the whole of the materials are delivered by sea, and for unloading them two extensive timber jetties have been constructed by the contractors at the site of the works. Four 10-ton steam cranes are kept constantly at work unloading ships as they arrive. At present about 35,000 tons of various materials are landed per month, and this quantity will be much increased. Work is carried on at the jetties by night as well as by day.

Portland Cement is brought round by sea from the Thames. It is conveyed in sacks, an average of 2,200 tons being delivered per month; this will soon be largely increased. The sacks are loaded into wagons, and conveyed to the cement stores, where it is tipped in bulk until required to be used. There are two stores, one capable of storing 5,000 tons, and the other somewhat less.

Granite is also brought by sea, about 2,500 tons being delivered per month. The stones arrive dressed ready to set in the work. On being landed the stones are conveyed to portions of the yard set

apart for stacking them. Two 10-ton Goliaths of 60 feet span are used for stacking the granite, and for loading it up again when required to be used.

Limestone is brought in barges from the local quarries, is discharged at the jetties and stacked in the yard by steam cranes. About 1,500 tons are landed per month.

Shingle and Sand.—Very large quantities of these materials are required for concrete. About 25,000 tons are delivered per month during fine weather, and arrangements are being made for about double this quantity. They are obtained from Start Bay, where they are dredged up near the shore. For this purpose two suction dredgers are employed; one delivers into barges and the other carries its own load. A powerful tug is provided for towing the barges to and fro, a distance each way of about 30 miles. The dredger delivering into barges can send 2,000 tons per 24 hours, the other dredger conveys about 600 tons each journey, making one journey a day. When the barges or dredger arrive alongside the jetties, their cargoes are discharged by Hone's grabs attached to the cranes. Four of these grabs can discharge a cargo of 1,000 tons in about four hours. The cargoes are deposited from the grabs into wagons and removed to be tipped on the storage ground, whence the shingle is again loaded into wagons by hand, to be conveyed to the concrete mixers as required.

Broken Stone is occasionally used for concrete instead of shingle. The stone is obtained from the local quarries in the form of rubble, and crushed on the works to the required size by two of Baxter's stone breakers, which are worked by portable engines.

Timber in large quantities is floated in rafts from the timber ponds to the jetties and there loaded on wagons to be conveyed to various parts of the works.

Coal for the machinery is required in large quantities. The average amount discharged at the jetties per month is over 2,000 tons.

Building Operations.—The concrete is all mixed in Taylor's concrete mixers, of which there are six on the works. They are mounted on frames at such a height, that they can discharge direct

into skips on trucks beneath them. They are worked by gas engines. The leading feature of Taylor's mixer, Plate 112, is that, although it is a closed mixer and thoroughly mixes the materials by revolving on a horizontal axis, it does not require to be stopped either to receive its charge or to deliver it when mixed into the skips beneath. The materials are placed dry in required proportions in a hopper A, Fig. 6, fixed above the mixer C, and from the hopper they are sent into the mixer through the trunnion D on one side; the requisite amount of water, which can be regulated, is admitted from the tank B at the same time through the opposite trunnion E. The concrete when mixed is discharged into the skips through doors H, which are opened and closed by the sliding collar G worked by the lever F, and is conveyed on trucks to the required site, where it is deposited by steam cranes.

The masonry in the walls and docks is set by ordinary steam-cranes and by 10-ton steam derrick-cranes, the latter being used in positions where a greater length of reach is required than can be obtained by the ordinary cranes. All the piles in the cofferdam and in the temporary stagings have been driven by pile engines, specially constructed on the works for the purpose, and worked by steam winches with 8-inch cylinders. As there is a large quantity of permanent piles to be driven in foundation work, two of Sissons and White's pile engines have also been obtained. All the piling is in soft mud.

In works extending over such a large area, taking into consideration the depth of the trenches and length of the cofferdam, it was expected that large quantities of water would probably have to be dealt with. So far, however, very little water has been encountered in the shape of springs, and except in heavy and continuous rain there is not much work for the pumps.

The leakage from the cofferdam is very small and is easily dealt with by a 6-inch pump working occasionally. A list of the pumps in use or in reserve to meet emergencies is given in the Appendix.

Workshops.—The carpenters' shop contains two saw mills, one of which is worked by a gas engine and the other by a portable engine. The fitting shop contains a large number of lathes,

drilling and screwing machines, etc., which are worked off a shaft driven by a gas engine; blast fans are worked off the same shaft for the smithy and also for the cupola of the foundry. All repairs to the machinery and plant are carried out in the workshops, where a large staff of men are constantly employed in repairs of all kinds due to wear and tear and also to accidents.

The smithy contains 12 hearths and a steam-hammer, and adjoining is a foundry in which castings are made for repairs of plant and also for the permanent work, such as manhole covers, gratings, etc.

As the unloading work on the jetties and the excavation in various parts of the works are carried on by night as well as by day, it is necessary to provide some means of lighting up the works after dark. Electric light has accordingly been introduced over the greater part of the works and in the workshops. The works are lighted by 32 arc-lamps, and the sheds, trenches, shops, offices, etc., are lighted with about 350 incandescent lamps. The current is generated by two continuous-current bi-polar Tyne dynamos by Messrs. Scott and Mountain, running at a speed of 750 revolutions, giving an output of 135 ampères at a pressure of 220 volts. When only a portion of the lights are required, one dynamo can supply the necessary current. The dynamos are driven through counter shafting by one of Messrs. Davey Paxman and Co.'s 40 H.P. compound-engine with a steam pressure of 120 lbs. per square inch. A 40 H.P. compound engine by Messrs. Marshall and Sons is kept in reserve for emergencies. The boiler on the top of the Marshall engine supplies steam to either engine, a second boiler being kept in reserve.

In addition to the electric light, 40 Wells lamps are used in various parts of the works; these lamps have been fitted with special burners for the use of kerosene.

Appendix.

The Principal Machinery used on Keyham Dockyard Extension Works.

Machinery.	*Design.*
10 Vertical boilers.	
6 40-H.P. Winding engines. 6 20-H.P. " "	Robey, and Ruston and Proctor. Used for hauling wagons and mud scoops.
2 40-H.P. Fixed engines. 3 25-H.P. Portable " 7 20-H.P. " " 4 18-H.P. " "	Used for dynamos, pumps, saw mills, and other purposes in the yard.
4 15-in. cylinder Locomotives—6 wheeled. 4 12 " " " 4 " 4 10 " " " 4 " 2 9 " " " 4 "	Barclay, Manning and Wardle, Hunslet Engine Co., Hudswell Clarke, and Hawthorn Leslie and Co. Used in conveying materials from landing jetties and to various parts of works.
8 10-ton Steam cranes. 2 7-ton " " 37 5-ton " "	Smith, Booth, Whittaker, and Wilson. Used in landing goods at jetties, lifting materials from the trenches, lowering concrete and masonry into the trenches and setting masonry, and various other purposes. Four of the 10-ton cranes are fitted to be worked as steam navvies.
16 10-ton Derrick cranes.	Used for setting masonry.
2 10-ton Goliaths—60 ft. span.	Stothert and Pitt; used for stacking granite in yard.
10 Steam Winches—8-in. Cylinders.	For pile engines, &c.
4 Gas engines, for Concrete Mixers. 1 Oil engine, " " 4 Gas engines for workshops and yard.	Gas Engines, Tangye. Oil engine, Noble.
6 Dynamos.	
40 Wells Lamps.	

Machinery.	*Design.*
5 Rock drills, "Larmuth."	
4 ,, ,, "Little Hercules."	McCullock.
2 Air compressors.	
6 Concrete mixers.	Taylor.
2 Pile drivers.	Sissons and White.
4 Steam navvies.	Ruston and Proctor.
2 Stone breakers.	Baxter.
8 Grabs.	Hone.
4 ,,	Other makers.
7 Mud scoops.	

Pumps.	
1 18-in. Duplex.	Clyne, Mitchell and Co.
1 18 ,, Large rocker.	
3 12 ,, Centrifugal.	
2 10 ,, ,,	
16 6 ,, to 8 in. direct acting.	Wade and Cherry, Owen, and Bailey.

Floating Plant.

2 Tugs, 500 I.H.P.
2 ,, 300 I.H.P.
2 suction-dredgers—22 inches diameter of suction pipe.
2 800-ton steam hopper-barges.
6 1,250-ton ordinary hopper-barges.
12 smaller barges of various sizes.

Discussion.

The PRESIDENT said he was sure the members would wish to join in a hearty vote of thanks to Mr. Eliot for his interesting Paper. Mr. Whately Eliot was the resident representative of the engineer-in-chief for the great works that were being carried out under the Naval Works Bill at the Keyham Extension, which the members would have an opportunity of visiting that afternoon. He wished also that the members should record their thanks to Major

H. Pilkington, C.B., R.E., who was the engineer-in-chief, for the very cordial manner in which he had received the application that the Paper might be contributed to the Proceedings of the Institution.

Mr. James Mansergh said it was always very interesting to hear an account of the planting of a big job by an experienced and enterprising contractor, and it was perfectly clear from the description given by the author that nothing could have been better than the way in which the Keyham Works had been started and carried on. The only novel piece of plant he had noticed was the mud-scoop. Fortunately he himself had not had to work in mud for the last few years; he was working now principally in very hard rock. The machine mentioned in the Paper and shown in Plate 110, would, he thought, be a very awkward thing to guide, and he should like to know how it really was guided across the mud. It would be interesting to know what it cost to move the stuff, for comparison with the experience of other appliances in other places. He noticed that the works had been lighted by electricity, but nothing was mentioned of the Lucigen light which had been used very largely, and which was a very good light. Where electricity had been used with big arc-lamps, the shadows were exceedingly black, and accidents had happened on that account. On his own works men had fallen down deep trenches from this cause. He hoped that afternoon to see the works with the party of members who were going to Keyham, and he had no doubt the visit would be an exceedingly interesting one.

Mr. Whately Eliot in reply said the guiding of the mud-scoops was a difficulty, and was in fact the main difficulty in the use of them. It was simply impossible to guide them, for as soon as the scoops began to work, and formed a very shallow groove, they could not be got out of the groove again. With regard to the Lucigen lights, they were being improved every year, and he mentioned at the end of the Paper that they had in use forty of the Wells lights, which were an adaptation of the Lucigen, containing the very latest improvements. They were found most useful in various parts of the

(Mr. Whately Eliot.)

works where the electric light was really dangerous. He should be very glad that afternoon, when the members visited the works, to answer any questions and give any information that it was possible to give about the works.

The PRESIDENT was sure that the members were very grateful to Mr. Whately Eliot for promising to guide them, and give a further description of the works. As Sir Frederick Bramwell said, it would be "a personally conducted tour."

THE MACHINERY OF H.M.S. "PROSERPINE" AND H.M.S. "PSYCHE," AS ILLUSTRATIVE OF THE WORK DONE AT KEYHAM, PARTICULARLY WITH REFERENCE TO THE PRACTICAL TRAINING OF ENGINEER STUDENTS.

By Mr. ROBERT MAYSTON, R.N.,
Chief Engineer, H.M. Dockyard, Devonport.

For some years, in addition to the general work of repairs to the machinery of ships, there has been continuously new machinery in course of manufacture. The ships for which the machinery has been manufactured at this dockyard comprise the following :—

Pheasant, Partridge, Lapwing, Ringdove	each of 1,200 I.H.P.
Phœbe	7,500 I.H.P.
Astræa	9,000 ,,
Talbot	9,600 ,,
Phœnix, Algerine	each 1,400 I.H.P.
Proserpine, Psyche	each 7,000 I.H.P.

and at the present time the engines and boilers for H.M.'s sloops "Rosario" and "Vestal," each of 1,400 I.H.P., are in progress.

The designs are worked out in the chief engineer's drawing office, receive Admiralty criticism and final approval before the work of manufacture is put in hand, and, with the exception principally of the steel castings and larger steel forgings, such as shafts, the various parts of the machinery are made and fitted at the yard. It is thus seen

that each entry of engineer students of recent years has, during its course of training, had the opportunity of witnessing the construction of, and taking part in the manufacture and erection in the shop and on board the ship of at least one set of machinery for a warship, involving the most up to date practice of the time.

Of the two latest completed ships above tabulated, the "Proserpine" and "Psyche," the engines and boilers of both were manufactured at Keyham, but in the case of the first named were fitted on board at Sheerness, whereas in the "Psyche" the whole of the work, both manufacture and fitting on board, was carried out at Keyham. Both are third class cruisers of a type of which there are several in Her Majesty's navy, either completed or under construction. The machinery comprises in each case two independent sets of triple-expansion engines, each with three vertical cylinders of diameters $20\frac{1}{2}$, 33, and 54 inches, the length of stroke being 2 feet 3 inches, and were designed to obtain with each set 3,500 I.H.P., or 7,000 I.H.P. with both sets, the boilers being worked under air pressure, and the steam pressure available at the engines being 250 lbs. per square inch.

Arrangement of Engines.—The general arrangement of the engines is shown on the illustrations which accompany this Paper. Plates 113 and 114 give views of the engines taken from forward, and Plate 115 a view taken from aft. Plates 116 and 117 give elevation and plan of the engines, showing sections through the cylinders and disposition of the columns, bearings, &c., and Plate 118 shows the elevation and plan of the arrangement of the machinery throughout the ship, giving positions of auxiliary engines, &c.

The cylinders are independent castings, the high-pressure and intermediate-pressure unjacketed, and the low-pressure jacketed; the working barrels of the latter are made separately, and the pressure of steam arranged for in the jackets 45 lbs. per square inch.

The slide valves of the high-pressure and intermediate-pressure cylinders are of the piston type; those of the low-pressure cylinders are flat. This arrangement is very generally adopted, one reason being that with the flat valves there is less liability of leakage past

them into the condensers. The slide gear comprises the ordinary double eccentrics and links, with steam-starting as well as hand-starting gear. There is a cast-metal surface-condenser O to each set of engines, the circulating water passing through the tubes; the circulating pumps are of the centrifugal type, and are designed to be each capable of discharging 600 tons of water from the bilge per hour with steam of 200 lbs. pressure per square inch, exhausting into the atmosphere. Balance weights are fitted to the high-pressure and low-pressure cranks, and on the trials of the ships there was found to be practically no vibration, complete steadiness of engines being obtained at all speeds. The propellers are three-bladed, of the modified Griffiths type, and the blades are of manganese bronze. The diameter of propellers is 10 feet 7 inches, and the pitch at which they were set when tried was 11 feet 3 inches.

Boilers.—The general disposition of the boilers B is shown on Plate 118 of the general arrangement of the machinery throughout the ship. There are two boiler rooms, containing eight water-tube boilers of the Thornycroft type, capable of being worked at a pressure of 300 lbs. per square inch. The total area of fire-grate is 350·4 square feet, and the total surface of generating tubes is 19,515·5 square feet. The whole number of generating tubes in these boilers is 8,752, varying in diameter from $1\frac{1}{8}$ to $1\frac{1}{4}$ inch, the thickness of each tube being 0·116 inch. The trials were run with 20,508 square feet generating tube surface. Some tubes partially masked by brickwork at furnace ends were subsequently removed, the surface being reduced to 19,515·5 square feet. All tubes are zinc coated by electro-deposition on the outside, and are solid drawn by the cold process. The tubes are secured to the collector plates by the ordinary method of expanding. Water-pressure tests of 450 lbs. per square inch were applied to the boilers after manufacture in shop, again when placed in ship, and again after trials. Plate 119 gives a view of one of the boilers as built up in the boiler shop. Four independent feed-pumps are fitted, two main and two auxiliary, all of the Weir type. The main and the auxiliary feed-pumps have independent systems of delivery-pipes and feed-

valves, and the arrangements are such that each of the pumps is capable of feeding any of the boilers. An automatic feeding apparatus is fitted to each boiler, which with the slow moving feed-pumps provides a very efficient arrangement for maintaining a strictly uniform water-level. Steel is the material used in the main leads of steam pipes, and the pipes are coated externally by electro-deposition of zinc.

Forced Draught.—There are eight fan-engines F, Fig. 7, Plate 118, for forced-draught purposes, which on the forced-draught trials were capable of maintaining an air-pressure of 3·7 inches, with 663 mean revolutions per minute. The diameter of fans, which are double breasted, is 5 feet 6 inches.

Additional Machinery.—The machinery, apart from the main engines and boilers, comprises the following:—Two electric-light engines E, Plate 118, one steering engine S, one capstan engine, two reversing engines, eight forced-draught fan-engines F, four ash hoists J, one air-compressor A, two main circulating engines C, two main feed engines M, two auxiliary feed engines X, two fire and bilge engines G, two hot-well engines H, two distillers D.

Prior to the boilers being placed in the ship, one of the same type was tested to ascertain if its evaporative power would meet the specified requirements, steam pressure being maintained at 300 lbs., and steam exhausting into the atmosphere at that pressure. Particulars of results were as follows:—

Area of fire-grate	43·87 sq. ft.
Total heating surface	2,563·5 „
Steam pressure	300 lbs.
Mean air-pressure	3·2 inches of water.
Fan in use	1 in No.
Diameter of fan	5 ft. 6 ins.
Revolutions of fan per minute . . .	544.
Consumption of coal per hour . . .	2,920 lbs.
„ „ per sq. ft. of fire-grate .	66·56 lbs.
Thickness of fire	6 inches.
Total water evaporated per hour. . .	19,210 lbs.

Water per pound of coal from temperature of feed-water	6·58 lbs.
Equivalent evaporation from and at 212°	8·10 lbs.
Temperature of funnel	841°.

As is usual with H.M.'s ships, the machinery on completion was subjected to a series of trials which were required to be carried out to the satisfaction of the Admiralty Inspecting Officers. These trials comprised the following:—(1) A basin trial; (2) a preliminary trial at sea; (3) a trial of thirty hours' duration at 3,500 I.H.P.; (4) trial of eight hours' duration at 5,000 I.H.P.; (5) a four hours' trial at maximum power, during which the power obtained was required to be not less than that specified nor more than 5 per cent. above it.

A summary of the results obtained on the trials of the two ships is as follows:—

THIRTY HOURS' TRIAL AT 3,500 I.H.P.

		Proserpine.	Psyche.
Pressure of steam at Engines		lbs. 210	215
Vacuum in condensers,	Starboard	ins. 25·7	26·3
" " "	Port	ins. 26·7	25·3
Revolutions per minute,	Starboard	169·2	171·2
" " "	Port	168·3	170
Indicated Horse-Power,	Starboard	1,755	1,835
" " "	Port	1,889	1,811
	Total Horse-Power	3,644	3,646

EIGHT HOURS' TRIAL AT 5,000 I.H.P.

		Proserpine.	Psyche.
Pressure of steam at Engines		lbs. 243	234
Vacuum in condensers,	Starboard	ins. 26·1	27
" " "	Port	ins. 25·8	26
Revolutions per minute,	Starboard	195	194·4
" " "	Port	193·5	193·6
Indicated Horse-Power,	Starboard	2,674	2,576
" " "	Port	2,662	2,522
	Total Horse-Power	5,336	5,098

FOUR HOURS' TRIAL AT 7,000 I.H.P. (FULL POWER).

		Proserpine.	Psyche.
Pressure of steam at Engines		lbs. 246	235
Vacuum in condensers,	Starboard	ins. 25·1	26·4
" " "	Port	ins. 24·2	24·4
Revolutions per minute,	Starboard	222·7	217·6
" " "	Port	220·5	218
Indicated Horse-Power,	Starboard	3,636	3,558
" " "	Port	3,509	3,473
	Total Horse-Power	7,145	7,031

The usual stopping and starting trials to test handiness of machinery were satisfactorily carried out, and all auxiliary machinery tested to ascertain its full compliance with requirements. An important condition attending these trials is that the water in the boilers must remain fresh throughout. It was required that, should there be any admixture of sea-water, the cause must be ascertained and the trial repeated after the necessary adjustments have been made. The freshness of the boiler-water and feed-water is determined by the nitrate of silver test, and by the use of a special sensitive hydrometer. Also on the thirty hours' trials at 3,500 I.H.P., it was required that all losses of fresh water caused by steam and water-leakage should be made good by the evaporating plant.

On conclusion of the trials above enumerated, the machinery was opened up in the usual manner for examination and for the satisfaction of the inspecting officers. Also a water-pressure test of 450 lbs. per square inch was applied to the main and auxiliary steam-pipes, and all joints were found to be perfectly tight. The low-pressure cylinder-jackets were also tested to 150 lbs. pressure with similarly satisfactory results.

The opening up was satisfactory, and everything appeared to indicate durability and efficiency.

Further Trials.—Subsequently to the opening up and after the ships were commissioned, a further trial of three hours' duration

Fig. 1. *View from Forward.*

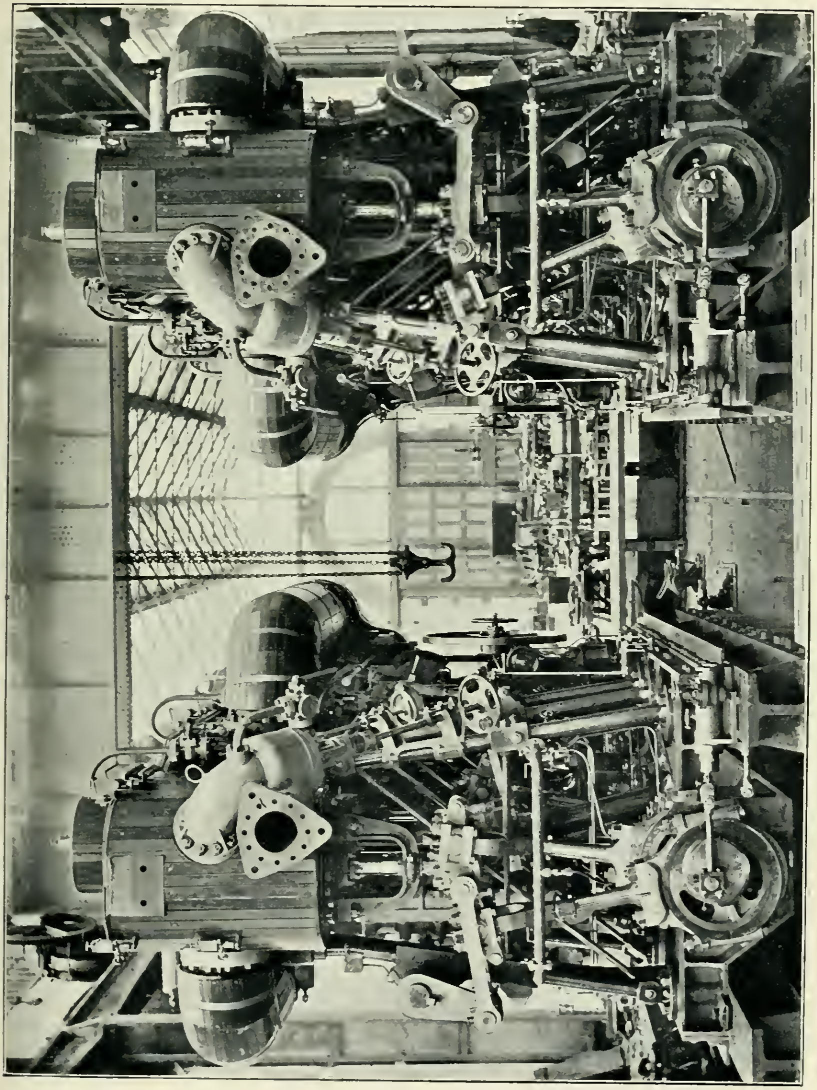


Fig. 2. *View from Forward.*

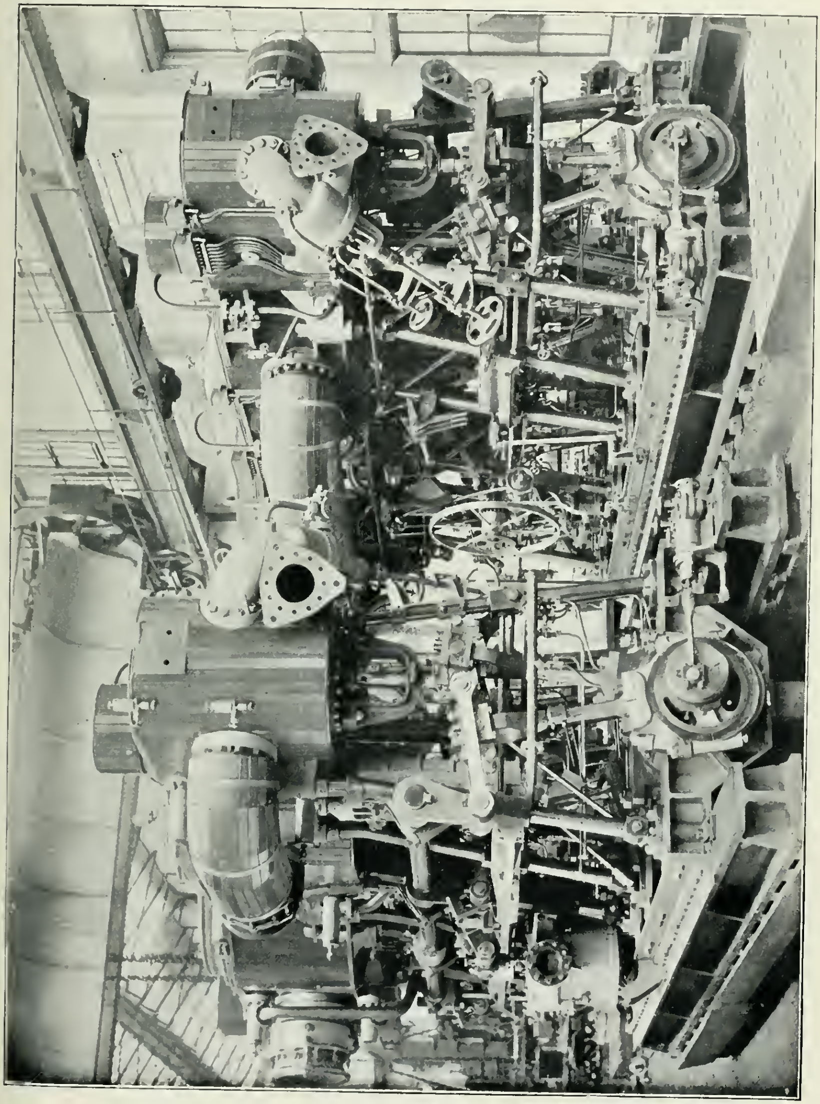


Fig. 3. *View from Aft.*

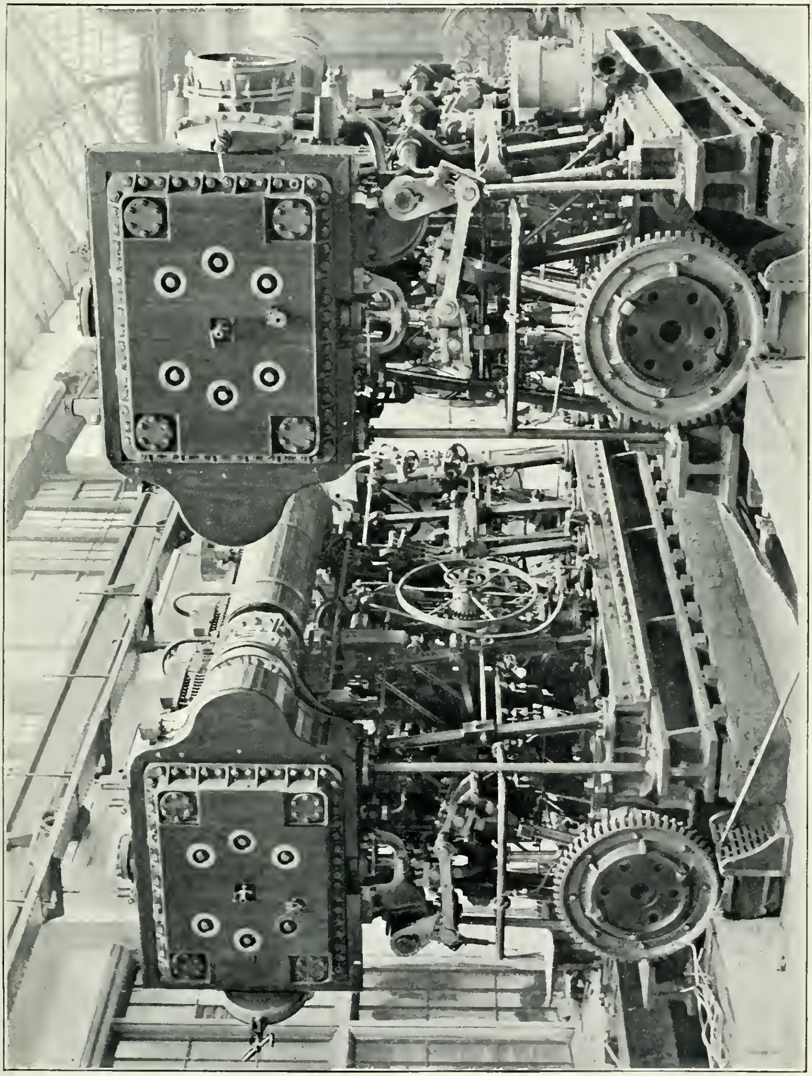
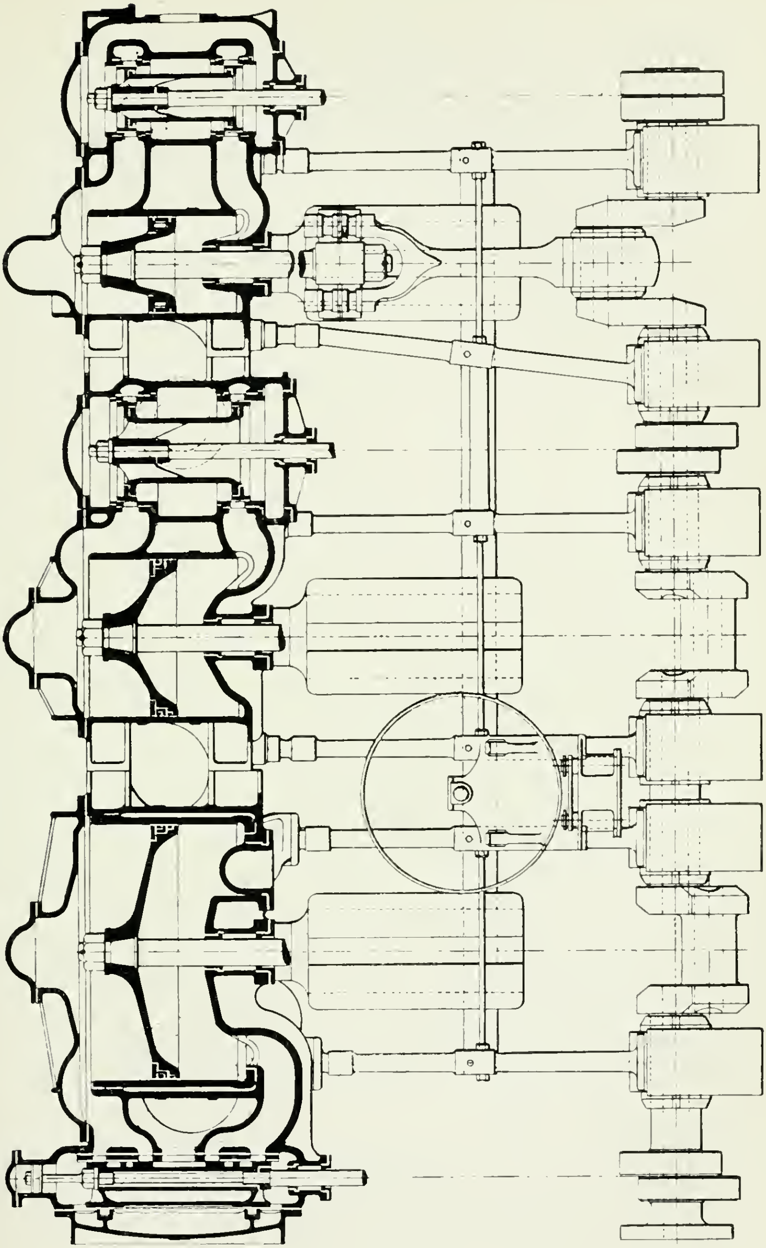


Fig. 4. *Elevation.*



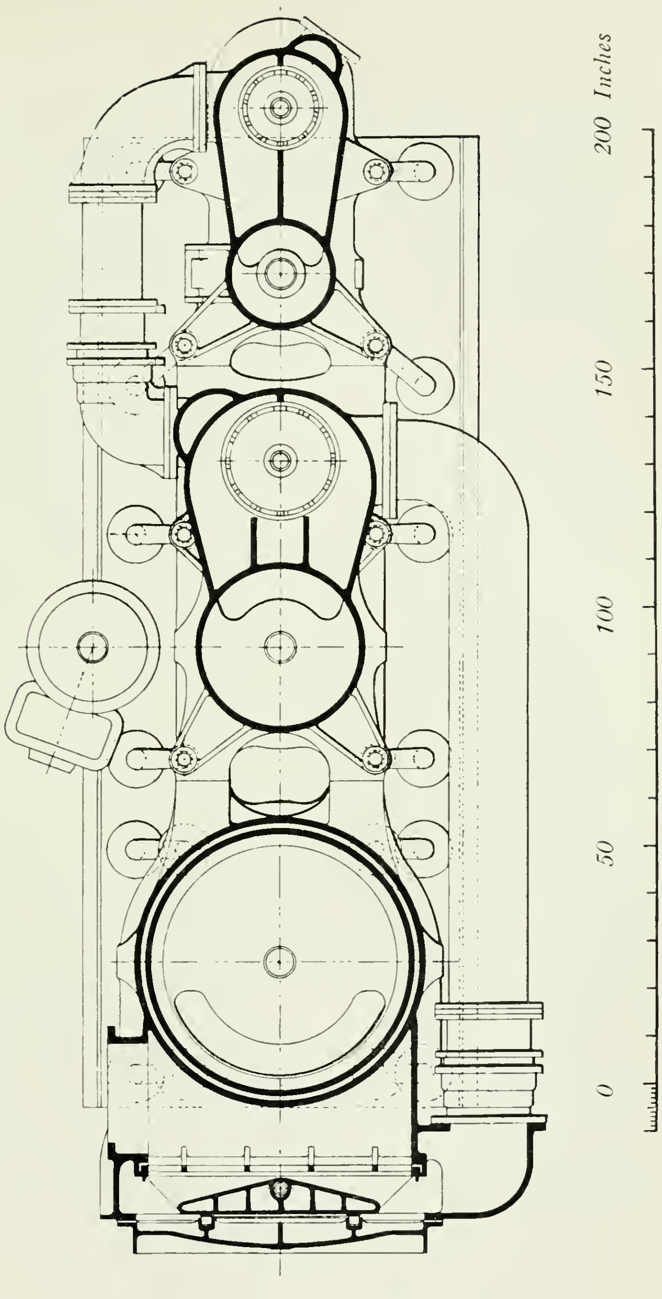
Scale, see Plate 117.

Plate 117.

MACHINERY OF H.M.S. "PSYCHE."

Arrangement of Engines.

Fig. 5. *Plan.*



MACHINERY OF H.M.S. "PSYCHE."

General Arrangement.

Fig. 6.

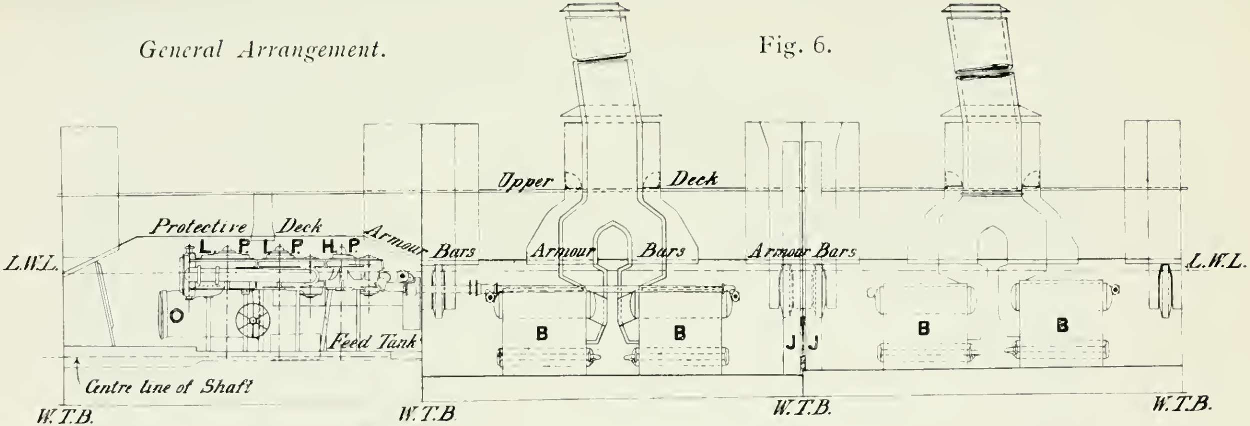


Fig. 7.

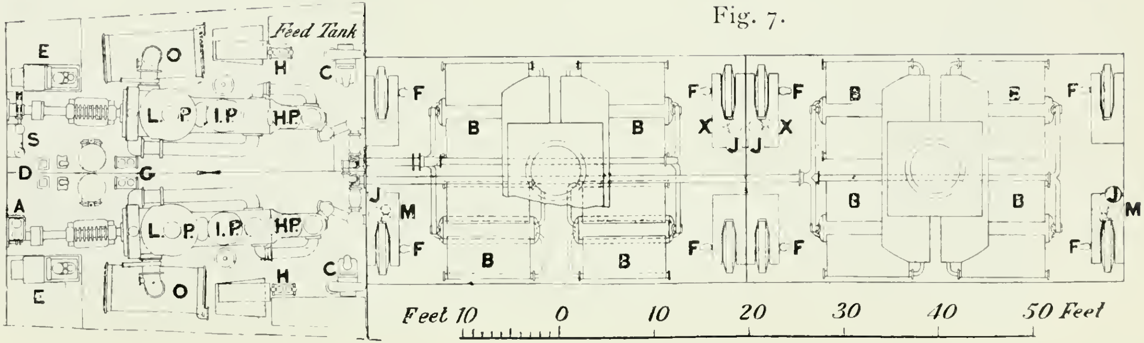


Fig. 8. *One of 8 Boilers.*

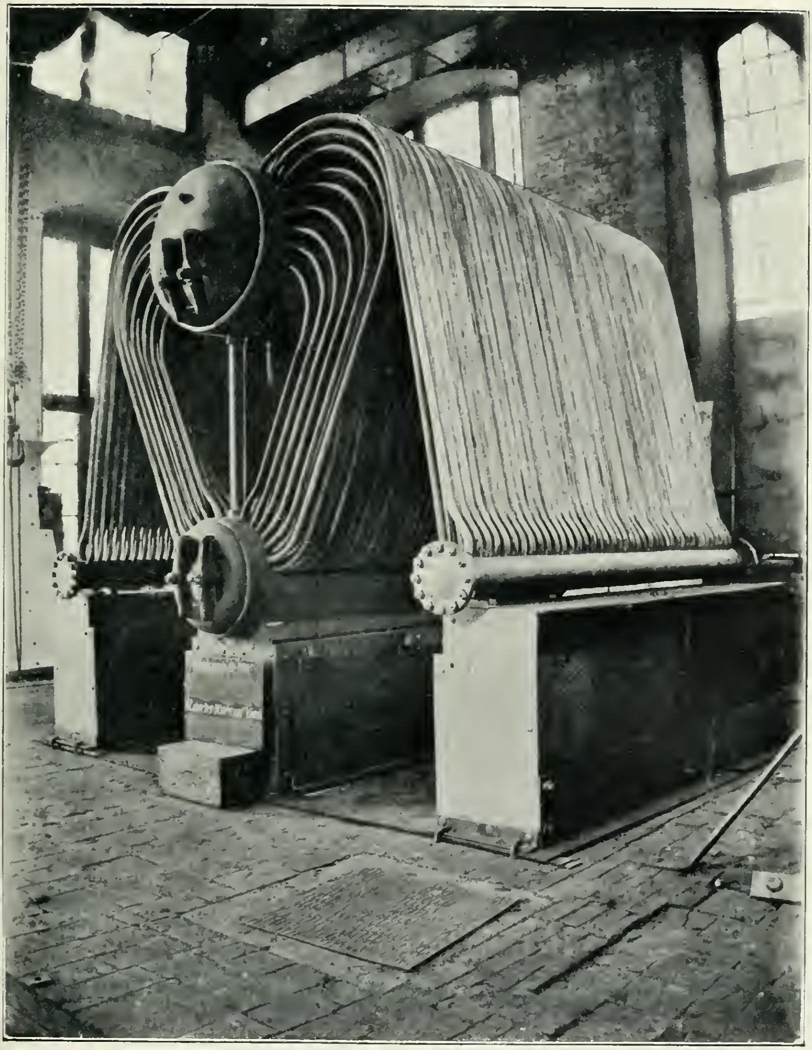
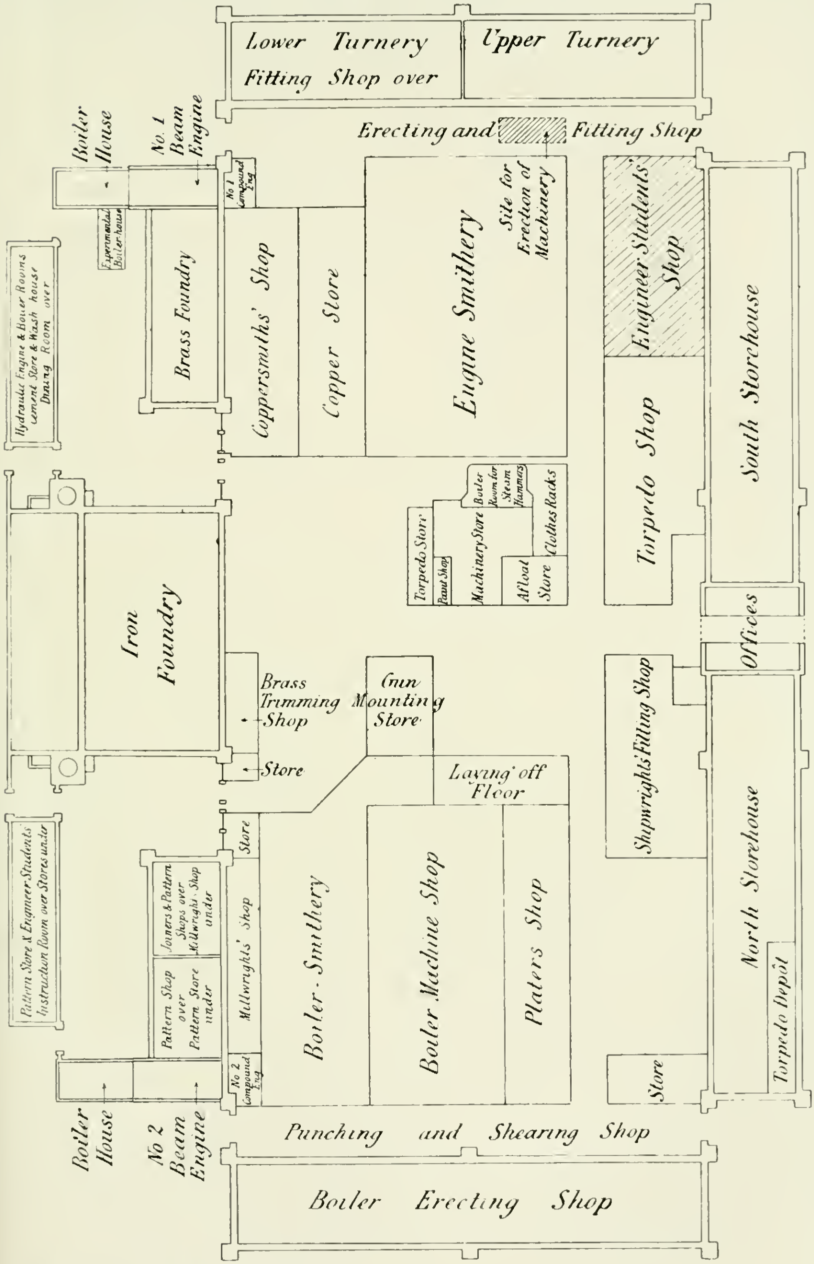
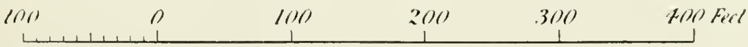


Fig. 9. *Plan of Keyham Factory.*



Mechanical Engineers 1899.



took place; the power authorised was 5,000 and the following were the results obtained:—

			"Proserpine."	"Psyche."
Pressure of steam at Engines		lbs.	239	235
Vacuum in condensers,	Starboard	ins.	25	27·8
" " "	Port	ins.	23·8	25·2
Revolutions per minute,	Starboard		186·5	195·8
" " "	Port		186·5	194·2
Indicated Horse-Power,	Starboard		2,501	2,609
" " "	Port		2,600	2,538
	Total Horse-Power		5,101	5,147

Shortly after the completion of the commissioning trials the ships left England for the North America and West Indies Station, the "Proserpine" last year and the "Psyche" in May of the present year. The procedure as regards these two ships was practically similar to that carried out in all new ships, and illustrates the tests to which machinery is subjected before being finally accepted by the Admiralty, whether the machinery has been manufactured by a private firm or at a dockyard, and before the ships are permitted to depart on home or foreign service.

Training of Engineer Students.—The "Psyche's" machinery, as well as that for other ships previously constructed or now under construction at Keyham, has afforded excellent opportunities for the efficient training of the engineer students, who are being instructed both theoretically and practically to enable them to become engineer officers in the Royal Navy. For the last eleven years Keyham has been the only Admiralty training ground for these officers. The number of students at the present time is 192. An entry is made once each year, during the first or second week in July, following a competitive examination held by the Civil Service Commissioners in the previous April. The period of training is five years. Throughout this time they undergo an educational course at the Royal Naval Engineering College under Professor A. M. Worthington, F.R.S., whilst their practical training is obtained in the dockyard at Keyham, and the work they perform is as far as possible real. They take a considerable part in the repair and manufacture of machinery, and in

the cases of the two ships which have formed the basis of this Paper, they have had a very large interest, more so in the "Psyche," for the reason that they have been able to follow the manufacture of her engines and boilers right through to the time of the ship going to sea, whereas in the "Proserpine," as previously mentioned, the engines and boilers were sent to Sheerness to be fitted in that ship, and the experience to be gained by seeing them fitted on board was not obtainable.

As illustrating the part taken in the manufacture of new machinery, reference need only be made to that of the "Psyche," and the following work was entirely carried out in the engineer students' fitting shop :—the two surface-condensers were tubed and tested ; the two fire and bilge engines, eight fan-engines, two hot-well engines and pumps, two circulating-engines and pumps with auxiliary air-pump, and the two reversing-engines in connection with the slide-valve gear, were completely fitted up from the rough forgings and castings, including all machine and fitting work. In addition, a large number of minor fittings, such as cocks, valves, &c., passed through the hands of the students. It should be noted that the work just enumerated is an indication of what is performed by the students in the early part of their training, that is, during the first half of it, and its class is such as to offer every possible attraction for a student commencing a marine engineering career; at least this is the object aimed at, and judging by results there is every reason to assume it has been successfully attained.

Plate 120 is a plan of the workshops at Keyham, showing the position of the fitting shop appropriated for the training of the engineer students, relatively to the principal fitting shops of the chief engineer's department. It will be seen that they are so close that the students are enabled to watch any erection of new machinery; in fact, it is part of their instruction to be shown the nature of the work as it progresses, and they are afforded every facility.

It may be of interest to give the exact training an engineer student undergoes at Keyham during the five years he is under instruction preparatory to his appointment as an assistant engineer, R.N.

First year's Training.—On entry he is engaged on practice work with the hammer and chisel, and after a short time commences engine fitting (useful work).

Second year's Training.—For nine months he is employed at the lathe, and the remaining three months at other machines. During the second year a half-day per week for the greater part of the year is spent in sketching details of machines and parts of machinery.

Third year's Training.—Eight months are spent in engine fitting in the students' shop, one month he is sketching details and learning the principles of construction of machinery used in connection with the discharge of torpedoes, such as air-compressing machinery, torpedo tubes, both submerged and above water (the latter as made and placed on board "Psyche,"), and the remaining three months he is employed on repairs to engines, &c., of ships afloat, or as the opportunity presents itself, such as in the case of "Psyche," in fitting new machinery in ships.

It may here be observed that the testing machine for materials is placed in the students' fitting shop, and arrangements are made for the students in turn to become acquainted with the tests and the methods of carrying them out and of recording them, all very important matters in connection with an engineer's training. All the materials used in the manufacture of "Psyche's" engines were so tested in order to ascertain if they complied with requirements as laid down in specification; for instance, in the case of the gun-metal used the tensile strength must not be less than 14 tons, with an extension in 2 inches of length of $7\frac{1}{2}$ per cent., and in the case of high-tension cast bronze such as used for the "Psyche's" propeller-blades, the tensile was not to be less than 28 tons with 15 per cent. extension.

Fourth year's Training.—The first six months are a continuation of the last three in the previous year, followed by one month in the coppersmiths' shop, where the short time renders it necessary their work should be more or less of a practical character, such as fitting

patches, branches, and flanges, soldering and brazing, becoming acquainted with the method of running white metal into bearings, and making sketches of the principal apparatus and processes generally appertaining to coppersmiths' work. This is followed by one month at smithing, in which the work is also of a practical character such as welding and light forging. Then follow one month in each of the pattern shop and brass foundry, and two months in the boiler shop, in the last of which he obtains knowledge of riveting, tube rolling, &c.

With reference to the boiler shop there are invariably new boilers under construction, and all descriptions come under repair or observation. At the present time Belleville boilers are being manufactured for the "Vestal," and tubes are being prepared for boilers of the small tube type already in existence, including the following descriptions, Thornycroft, Yarrow, Reed, Mumford, Blechynden, Du Temple. Also the Babcock and Wilcox boiler is under observation. During the third and fourth years one evening a week for two hours is appropriated for instruction in drawing under the direction and supervision of experienced draughtsmen.

Fifth year's Training.—One month is spent in the pattern shop and one month in the foundry similarly to fourth year, doing useful work; and three months fitting on ships afloat. Two months are appropriated for obtaining some acquaintance with the elementary principles of ship construction and the fittings of ships. The remaining five months are spent in the drawing-office learning engine drawing and design, the latter part of the time being occupied in the preparation of a drawing from his own sketches, which drawing is required to be done to enable him to pass into the Navy.

In order that the students may become acquainted with the working of machinery and the duties connected with the engine room when under way, the Admiralty have set apart H.M.S. "Sharpshooter" for the purpose, and classes are taken from March till October. During March the ship is steamed in the basin, and each third-year student is afforded the opportunities of actually performing the operations of laying and lighting fires, getting up steam, opening

and regulating the various valves, attending to the working of the engines and boilers, and learning the various duties of the engine room. The third-year students are divided into four classes, the course for each class lasting one week, four days under steam, the remaining two days for repairs, examination, &c. From April 1st to September 30th (except during examination and vacation times) the "Sharpshooter" is steamed under way by fourth and fifth-year students on two afternoons and one whole day a week, when all duties, connected with the working of the engines and boilers and examination and repairs after steaming, are carried out by them. Each student by the end of his fifth year has passed through, in addition to the preliminary stage in the third year, four courses of steaming under way, each course of two weeks' duration.

At the end of the season the ship is laid up for repairs, which are largely effected by the students themselves during the winter months.

It should be noted that the "Sharpshooter" has triple-expansion engines and was the first ship in H.M. Navy to be fitted with Belleville boilers, so that the steaming instruction afforded the engineer students by this ship is of very modern character.

Lectures on marine engineering are given to the students of the various years by officers of the chief engineer's department at Keyham, 18 per annum to the fifth year and 12 to each of the other years. The time devoted to the "Sharpshooter" and to lectures is taken out of the students' working hours in the dockyard, which comprise four forenoons and five afternoons, the two remaining forenoons are devoted to educational subjects distinct from the dockyard, and under the direction of the head master.

Sir William H. White, in his Presidential address, delivered to this Institution in April last, gave the various descriptions of machinery with which the modern warship is now supplied, and it goes without saying that with the growth of this machinery the necessity has increased for giving the officers, who will be mainly responsible for its efficiency, every opportunity for becoming familiar with it, and of becoming up-to-date naval engineers.

The facilities afforded at Keyham for the acquirement of a thoroughly practical training, place the Royal Naval Engineering College in the foremost rank as an institution for obtaining a sound knowledge of mechanical engineering. The facts that as soon as possible after entry the student is employed on useful work, the various courses of instruction which are arranged to render the knowledge of marine engineering obtained as complete and as comprehensive as possible, the facilities afforded for acquaintance with running machinery, the constant contact throughout the training with experienced workmen, the frequent opportunities afforded for obtaining information from the officers who have charge of the training, all go to indicate that nothing is spared to make the training of the engineer student as complete as possible.

It has been thought that the subject could be best placed before the Members of the Institution of Mechanical Engineers by associating the manufacture of the machinery of H.M.S. "Proserpine" and H.M.S. "Psyche," in which the students themselves have had considerable interest, with a description of the training undergone. It only remains to say that a better idea can be obtained by a personal inspection of the workshops at Keyham and the Royal Naval Engineering College itself, and that it will be considered a privilege to give the Members of this Institution any further information desired.

Discussion.

The PRESIDENT said that Mr. Mayston was in charge of all the marine-engineering operations at the Dockyard, and of the magnificent factory which had been standing for over forty years, and it was still a model of what a factory should be. On behalf of the members he desired to offer to Mr. Mayston the best thanks of the Institution for the very valuable Paper he had just read. It described not merely the important engineering work done under Mr. Mayston's direction, but (what he thought was of perhaps greater value to the Institution)

it gave the details of the training of the modern naval engineer. In considering the proceedings at that meeting, it occurred to him that many of the members of the Institution would be glad to know what that training was like. There was no doubt that the wider the field became from which naval engineers were drawn, the better it would be, and it appeared to him that there were not a few members of the Institution who had sons to start in life, who might be glad to know the way in which the Admiralty entered and trained its engineers. It was within the knowledge of the Council of the Institution, but was not generally known to the members yet, that the Council, in connection with its entry upon the new house and the adoption of certain new methods of procedure, had taken into consideration the desirability of interesting the Engineers of the Royal Navy in the work and the business of the Institution. On behalf of the members, the Council had communicated to all the naval engineers a statement of the objects and purpose and method of working the Institution, and had given them to understand that the Council regarded their position, training, and standing in the service, as ample guarantee of their professional qualification. The Council ventured to hope that a great many of that very important body of naval officers would be induced to join the Institution, and that not merely in their own interest, because the Council thought the Institution could offer them something that was worth having, but in the interests of the Institution also, as bringing amongst its membership a body of men thoroughly trained as mechanical and marine engineers, and undertaking very important duties in the Fleet. He was glad to be able to add before the discussion began, that although that invitation had only been issued a few days, they already began to see that no mistake had been made in informing the naval engineers of the good feeling which the members had towards them. He would now ask Sir Frederick Bramwell to open the discussion.

Sir Frederick Bramwell, Bart., Past-President, said he was very much complimented by the request, but he had not in any way prepared a speech on the Paper, and beyond saying that he thought it was extremely clear and most interesting with regard to the

(Sir Frederick Bramwell, Bart.)

education of naval engineers, he really had very little to say. The facts set out were so self-evident that they did not require any discussion. He did not think he could usefully occupy the time of the members any longer, and with the President's permission he would sit down.

Mr. JOHN I. THORNYCROFT, Member of Council, said he need not say he was considerably interested in the machinery which had been described, and he also felt greatly interested in the education which had been devoted to the students, their training, the intimate connection between their book-work and their observation of practical work, and their practical experience of how the engineering constructor could do his work. He thought the Paper showed how ships which were so well and so quickly built, could also be efficiently handled in the engine room when in use. With regard to the practical part of the ship's outfit, the boilers were the principal features which much interested him. He was glad to see in the Paper that it was found after examination that all was well with the boilers. With regard to the details of the particular boilers, he regretted there was not the improvement which was recently made, in dividing the inner nest of tubes by an additional wall of tubes made so as to prevent the gases taking, what they naturally did, the shortest course to the funnel, and therefore not distributing the heat so well. His firm recently made two boilers for a vessel with that improvement, and found a decided advantage in the coal consumption on trial. He thought the Institution was greatly indebted to the author for the admirable Paper he had brought before them.

Professor W. CAWTHORNE UNWIN, Honorary Member, said he had had a long experience in connection with the education of engineers, and there was no question that the part of the Paper which related to the education of engineers for the Navy was of extreme interest. People in England were beginning to realise that the education of the engineer was a matter even of national importance. The Americans were spending large sums on the education of their engineers, very large sums indeed in comparison

with anything that was being done here, and they were developing systems of education which seem to be giving them an advantage in their commercial relations with other countries. Mr. Mayston had described the course with such great clearness, that it did not leave much room for discussion. He supposed one might recognise at once that at Devonport they had to deal with a very homogeneous class of students, homogeneous both as to their education on entrance, and as to the object they pursued in their studies, and therefore there was a chance of dealing with students in an almost more thorough way than was possible in other institutions. Another point which struck one was the exceedingly large proportion of the education which was devoted to practical work. That again came from the fact, he supposed, that the students were being educated rather for the management of machinery than for the design and invention of new machinery. In that respect their education necessarily differed somewhat from the education at other institutions. At the same time the real problem, as it seemed to him, of the engineer's education, wherever it was carried on, was properly to find some way of combining practical and theoretical education. They were driven in all the schools of engineering to have at least a practical department, and by a practical department he would include not only the workshop, but also the drawing office, because he had found more and more that it was useful to increase the instruction which could be given at the drawing board. He did not think there was any reference in the Paper to one point. As he understood, part of the students, who had been through the whole course, were drafted off for higher education elsewhere. There again one touched on a point of very great importance in education. If they were to make the best use of the brain material they had in industrial work, some system was required for straining out stage by stage first the students only capable of profiting by a lower course of training, and then the best students fit to undergo a higher course of training. Perhaps Mr. Mayston would add, whether he was right in thinking that the best of the students received even a larger theoretical training than was indicated in the Paper. With such a staff of well-trained students who had every year to carry out

(Professor W. Cawthorne Unwin.)
steam trials, one hoped that sometime or other they would be able to make the trials a little more complete than those given in the Paper.

Mr. J. Owden O'Brien, said the chief interest of the Paper lay in the practical educational point of view, and in the fact that the engineering students were turned out not as kid-glove engineers, but as practical engineers after their term of four or five years' studentship. In some of the larger engineering centres a good deal had been done by technical schools and by colleges to train engineers, but they seemed to him to a large extent to cut off the practical work from the theoretical. Professor Unwin had made some remarks on the theoretical side of the question, and at such colleges as Owens College in Manchester, and University College in Liverpool, a thorough theoretical education was given to engineers with a certain amount of practical work in a small laboratory. But the result after five years' training in many of those places was that a man could not get into a works anywhere. He knew of one man in particular who spent five years at college, leaving it with an engineering degree, and in the whole of Manchester he could not find a single works that would give him a job, because he was without practical knowledge or training. It seemed to him that the difficulty was, that in the different colleges and the technical schools there was no affiliation between the workshops and the theoretical work, and that if a youth wanted to be an engineer he had to serve his apprenticeship in a works first, and after spending five years in gaining a practical knowledge, he must spend three or four years at college afterwards to get a theoretical knowledge. He did not know whether the Council of the Institution could do anything in the matter, or whether the colleges which Professor Unwin represented could come to some agreement with the engineering proprietors in their districts, whereby students at the colleges could spend part of their time at the colleges and part in engineering works, so that after spending five years as a student or apprentice, they would be able to do something, and not be like the youth he referred to, who, with an engineering degree, left engineering and became an estate agent.

Mr. H. R. Champness said he only wanted to supplement the Paper by one or two remarks. The President and Professor Unwin, whom Mr. Mayston and himself were very glad to see again as two of their former instructors at the School of Naval Architecture, South Kensington, would remember that at that time it was considered advisable to recognise the very close connection between naval construction and marine engineering. Provision was therefore made in the curriculum of studies, that the marine engineer should have a course in naval construction, and that the sessional examination should take papers in that subject; and, on the other hand, that the student of naval architecture should have instruction in steam, and take a corresponding paper in that subject. The marks assigned to those papers were the same, so that the two classes of students in the final examination list were not placed at any disadvantage in that respect through one taking a paper in a subject more particularly belonging to another. That connection was represented to some extent still in the course of training for the engineering students at Keyham. It was arranged that they should have opportunities of becoming acquainted with the structure and fittings of the hull of the ship. Since the time of which he had spoken, electricity had played a much more important part in ships' fittings, if indeed it could be said to have played any part at all then, and the consequence was that the students now took a course of electricity and a short course in ship construction; and so the connection between their purely marine engineering training and the naval construction branch was maintained, he thought to their advantage.

Mr. C. L. Eclair Heath said that as one trained in a manner very nearly similar to the engineering students at Devonport, in fact trained in the same manner as the President, and at the present time engaged in training others in the north of England, where things were different from what they were in the south, he thought he could say a little that would supplement the Paper. There was one point which might have been made more prominent, namely, the combination of the theoretical side with the practical side. As two

(Mr. C. L. Eclair Heath.)

of the speakers had hinted, the general system of education in the country was sadly wrong in not combining the theoretical with the practical work in a better manner. As Mr. O'Brien said, after five years' training in a technical school or university college, a student cannot get a situation. That experience was not confined to Manchester, and he knew of other places where a similar difficulty might be found. At Devonport for five years the students were engaged in practical and theoretical work, the latter not in the evenings when they were tired and went to sleep, but in the morning; and in the afternoons they had first-class lectures given to them. Those lectures were given in the most systematic manner. At the beginning they had drilled into them mathematics, mechanics, and other subjects which formed a fine basis of engineering. Then there was built on that foundation steam engineering or naval architecture, as the case might be. That method was wanted in the north of England. At Hull technical schools they were trying to work with the masters of the engineering works, and he was very glad to say that Mr. A. E. Seaton, the head of Earle's engineering firm, had co-operated with them very heartily. Having been trained originally in the same way as the President at Devonport, Mr. Seaton could appreciate the value of his previous education. Some of his apprentices came to the school by day, and sometimes they visited works in the morning. They came in various batches according to their qualifications. He had not succeeded in getting the assent of other people to a similar course, except that they would now shorten the apprenticeship of students who had taken courses at the schools. A good number of the members came from the north, and represented firms of importance, and he wished to elicit their sympathy on behalf of the student, that the latter should be given time to get that education not only by night but by day. Could it not be arranged that some organised work should be done at the technical schools by day? The present system of education under the Science Department would always be a failure, so long as it was only work done in the evening. When work was done by day, as in Professor Unwin's Institution, it must be of a first-class nature; but only certain individuals could afford or had the leisure to get to such a place as

the Central Institution of the City and Guilds of London. In every town now, including Devonport, there was a good technical school, but many of the students only attended in the evening. If by some means or other, either as an institution or individually as representing firms, the members could get some organised course, not in one town or one institution, but in every town and every technical school in the districts, then a new system of education would be started which would have a very far-reaching effect. Professor Unwin had spoken as to the desirability of drawing-office practice. He himself would give a little illustration of a student who had been three years only in an organised course. The third year he had taken a great deal of drawing-office work. The engineering department of the school were starting to design their own experimental engines, and that student had taken in hand the design of one cylinder and the apparatus pertaining to it, and his work was very creditable. He was only eighteen years of age. With the drawing-office experience that they now had, and with the still greater experience of laboratories and testing, good men could be turned out, and all that was wanted was the co-operation of the other people represented by the majority of the members.

Professor A. M. Worthington thought it might be of interest if he were to add a few words with respect to the educational instruction, as it was called, and deliberately called, that was given in the Royal Naval Engineering College, to a great extent independently of the dockyard work. The Engineering College at Keyham was the outcome of the old dockyard schools, which schools were found still in each of the Royal Dockyards. They had a tradition behind them, and an experience which in a very great measure guided the selection of subjects that were taught at the College. He did not think it was any exaggeration to say that no institutions in the country had had so large an influence on the progress of naval construction as the dockyard schools. That had been recognised by the President when he spoke of his own early training in the dockyard school at Devonport. It must be well known to many that a large number of those who held important

(Professor A. M. Worthington.)
positions in naval engineering or naval architecture, were originally trained at one or other of those schools. The schools had always been under the control of the Director of Studies of the Navy, that is, under the influence of Cambridge mathematical traditions, and the main subjects of training, certainly to within about twelve or thirteen years ago, were mathematics and mechanics. The success which had attended the schools had caused that tradition to be deliberately maintained, and much the same kind of training was still given at the dockyard schools as was given at the Royal Naval Engineering College. The chief change that had been made of recent years had been to extend the teaching of physics and of mechanical subjects, so as to bring in more of modern applied mechanics; but the selection still remained a limited one, and the education was still on those rather old lines. The amount of time devoted was not very great. For the ordinary student eleven hours a week were devoted to what was called "school" subjects. Those eleven hours were taken on two mornings a week, two evenings, and an odd hour on Wednesday afternoon. There were, however, certain voluntary classes, and the more industrious students could, for at any rate another two or three hours, attend the school voluntarily. That attendance, he regretted to say, had to be taken out of evening time, which, as the last speaker had said, was not the best time. The change from afternoon to morning hours was made many years ago, and was recognised by everybody as being a great improvement. The selection of subjects was determined very much by the limitation of the time, and he thought that where they differed from technical schools, in which engineering was taught, was in their efforts being limited to laying a very good foundation, chiefly in mathematics. A larger proportion of time was devoted to pure mathematics than in any other technical school. He asked the members to remember that the arrangement he described was one that had stood a very long trial. He had not, however, yet given quite a complete statement, because it must be mentioned that after training at Devonport the best twelve or fifteen of the students went for another year's training to Greenwich, and of those, one or two were retained for still further work at Greenwich, and might stay

there altogether for three years. It was to those specially picked students, whose training had taken eight years, that the prizes the Admiralty had to offer chiefly fell. They were really being trained for staff work. Professor Unwin had rightly conjectured that the apportionment of time was determined by the fact, that the majority of engineers at Devonport were to be trained for superintendence work at sea, and not for the purpose of designing new machinery. It was only the smaller number to whom such duties would fall, and these had a more prolonged course of training, and for them it was felt that the fundamental training in mathematical subjects was of the very highest importance, and even such extensions as had been made in the direction of physics and applied mechanics had been somewhat jealously looked upon by the teachers at Greenwich, who had noticed that, on account of the limitation of time, the ability in pure mathematics had been somewhat diminished. The point he wanted to emphasise, and which was really of considerable importance, was the fact that these oldest technical schools in the country, the dockyard schools and the engineering college which had sprang out of them, were carried on deliberately on lines which differed somewhat from the lines which it was attempted to follow for general engineering throughout the country. That was the result of experience, and, until the experience outside pointed to the desirability of a change, he felt sure that the Admiralty would follow the lines they were still pursuing.

Professor Robert J. Scott desired to say a few words, not on the subject of engineering education, but on the behaviour of the machinery which had been so ably described in the Paper. During the last eighteen years he had had exceptional facilities for observing the behaviour of Her Majesty's ships when on service in perhaps the most stormy seas in the world, seas so stormy that a well-known naval officer had said to him, "When I am in Australia or New Zealand, I always prepare for a gale of wind before putting to sea, and I invariably get it." It had been his good fortune on more than one occasion to be a guest on board those vessels. Speaking of the older vessels, when they met a head sea and the engines were in good working order, they held their own; but when the boiler tubes were

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leaking, they did not hold their own. Concerning the more recent vessels, he had seen letters in the English papers in which the machinery of English war-ships was compared with that of liners, to the disadvantage of the former. But during the period alluded to, or at all events during the latter portion of it, he had not known a single instance of serious trouble in the engine room, and he had never heard any complaint of the inefficiency of machinery. In fact, as a rule everything, that had been said, had been said in praise of it. Some years ago there was a flag-ship on the Australian station for, he believed, three successive commissions. That was H.M.S. "Orlando." She had been re-commissioned on the station, and had not paid a visit to home quarters, but during her last commission she made the record run from Christchurch to Wellington in New Zealand, and he was informed averaged a higher speed than on her trial trip. He was very glad of that opportunity as an entirely unbiassed and outside individual, who had had some experience of Her Majesty's ships when at sea, to be able to bear testimony to the excellent work done at Her Majesty's dockyards and the private yards, and the excellent character of the machinery. There was another point to which he might draw attention: some years ago when H.M.S. "Calliope" steamed out of Apia harbour in the face of a hurricane, the result was attributed to the use of Westport coal—a thing he was rather doubtful of at the time, for, on being tested, that coal gave only about the same evaporative efficiency as good Welsh coal. But about twelve months ago, in making some extended tests on the New Zealand coals for the New Zealand Government, he came across the remarkable fact that with the same draught roughly speaking about 50 per cent. more Westport coal could be burnt per square foot of grate per hour than Welsh coal; so that, in cases where economy was of secondary importance as compared with steaming power, he considered that Westport coal was undoubtedly the best. After a five hours' trial of this coal in a 10 N.H.P. boiler, the total amount of residue from ash-pan and fire-box amounted to only $1\frac{1}{2}$ lbs. The contents of the ash-pit were returned to the top of the fire during the trial.

Mr. A. Tannett Walker, Vice-President, said he had the pleasure of visiting the workshops at Keyham with Mr. Mayston, and he thought the members had a treat in store if they only saw what he had seen. The education the students were getting was of an excellent character, and supplied a great need. One of the speakers had said that in his experience a lad might get a scientific training, and even take a scientific degree, but when he came to seek work in Manchester he found it was impossible to get a situation. He himself had had some experience as a works' manager twenty years ago, and had kept himself in pretty close touch with works both in this country and on the Continent. His late father, who was a very experienced man and was a works' manager fifty years ago, had told him that on no account would he have a premium apprentice or a boy of any sort who could not earn his wages. The practice they had was not to take a premium, but if a bright boy came to them they were very glad to have him, and they hoped he would stop and succeed. In this world it was a question of brains. In the big works where there was such competition, it was a question of the worst man going to the wall and the best man going to the top. They tried to pick out the boys, and to help them, and he was sure that any intelligent bright fellow—if he had a degree in science all the better—coming to the works and showing that he could do work could get employment.

Mr. S. C. Davidson suggested that if Mr. Mayston could add to the paragraph under the heading of "forced draught" the diameter of the fan referred to, and the cubic feet of air discharged at the pressure mentioned, the information would be more complete.

Mr. Jenner G. Marshall said he thought there was one important point that had not been touched upon. The speakers had spoken mostly of the education of engineers from the scientific point of view, but there was another point which was most important, and which he was afraid in this country had hardly sufficient attention given to it, namely, the organisation of the work. In most cases students had a theoretical education, possibly a very good one, and a practical education, also probably a very good one, and very

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likely they combined the two; but he did not think there was any systematic education as regards organisation and carrying on work in bulk. They had details taught to them, but not the production of large quantities of work. He asked whether it would not be a good plan that some kind of education of that sort should be given to young men on starting life. There was another point. The other day he was in Brown and Sharpe's works at Providence, Rhode Island, where he understood they had about 100 pupils. Those pupils were all over the works, and they had the attention of the foremen in the different departments. At the head of those students there was a gentleman who was told off for their individual instruction, and who had no other duty than to go round and instruct the students, and deliver lectures to them in a class-room which was fitted up in the works. As regards himself, he had worked at Winterthur very much on the line that had been referred to by one of the speakers, namely, he had had the opportunity of choosing whether he would go to a class in the engineering college or work in the shops of the locomotive works during any hours in the day he considered most convenient, and he had found it a great advantage.

Professor Henry J. Spooner said there was one point he had been expecting every moment to hear referred to, and that was, the question of entering assistant engineers for service in the Royal Navy from outside colleges and works. He thought if the author of the Paper could see his way to add to it an appendix relating to the conditions under which young engineers were entered, more particularly giving particulars of the examinations they had to pass prior to being admitted to the Navy, it would materially increase the value of the Paper, and give a good deal of information that would be appreciated by the young engineer of the present day. He supposed engineers would never agree as to just that balance between theory and practice, which would produce the most satisfactory engineer for practical working purposes. In that connection he should like to call attention to a point that did not seem to be very clear. He understood from the Paper that the work done by the students at Keyham was supplemented by some kind of technical

training. For instance, he noticed on page 387 that "lectures on marine engineering are given to the various years by officers of the chief engineer's department at Keyham, 18 per annum to the fifth year, and 12 to each of the other years." He took it that the students who worked for the first four years received on an average one lecture a month on the all-embracing subject of marine engineering. It would add very materially to the interest of the Paper if the branches of marine engineering covered by that general expression were more clearly defined, and if one could see more clearly what continuity there was between those years of study in that branch of work; also if there was a time-table giving the number of hours the students spent upon each part of their theoretical work. Professor Worthington had particularly dwelt upon the subject of mathematics, and one would naturally gather from his remarks that not a few hours per week must be devoted to that particular subject alone. He thought Professor Worthington was responsible also for saying that eleven hours only were given to theoretical work in the whole week; so it would be interesting to know how many of those hours were devoted to pure mathematics. He should just like to say—and the remark was suggested by some words which fell from the lips of Mr. Tannett Walker, relating to the after career of students who had spent perhaps two, three, or four years in some school of engineering—that from his own experience in that direction he could perfectly bear out what Mr. Walker said. The students that passed through his hands at the school of engineering at the Polytechnic in London entered for a course of either two or three years, devoting, roughly speaking, the morning to theoretical studies and the afternoon to the workshops and laboratories. The aim was from the beginning to give the students such a training as would make them useful either in the drawing-office of an engineer or in the works, and he ventured to believe that they had been eminently successful in that respect. Their students experienced no difficulty in getting employment in the drawing office or in the works as improvers. From time to time students had gone up to the Royal Naval College, Greenwich, for examination, and had passed the by no means easy papers that had been set for the admission of outside engineers. In

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some cases those students had taken their technical course after five or six years' workshop experience, by devoting practically the best part of the day to theoretical studies. Other students, after passing three years in the school, had gone to the Clyde or Tyne, and had spent two or three additional years at the big yards, before going up for the naval engineering examinations.

Mr. H. GRAHAM HARRIS, Member of Council, said it appeared to him that the Paper really dealt with two separate subjects, one, a description of marine engines, and the other, the education of the engineering students at Devonport Dockyard, and that it had been discussed only from one point of view, and that point of view had been, if he might say so, a little mixed. The question of what education was to be given to a student was a question first, of what the student was capable of doing, and second, of what he was going to do when he had received that education. It must be remembered that there are many more jobs of £2 to £3 a week than jobs of £2,000 to £3,000 a year, and that the education and ability required for the two positions were absolutely and entirely different. Education at Devonport Dockyard was intended to provide men who would manipulate and work machinery of a more or less complicated character, which machinery was carried in "iron boxes" to all parts of the world. The "iron boxes" were designed by the President so as to withstand the sea and the wind met with in their journeys, which they did most successfully. He himself was certain that after all the consideration which had been for years devoted to the question, after all the efforts to make the education of these students that most fitted for their needs, and after all the developments that had occurred in the mode of training and in the machinery to be placed under their care, the training given to them must of necessity be a most satisfactory example of what such training should be, to provide the men required. The question of whether a little more technical education, or a little less technical education, or a little more scientific education, or a little less scientific education, was best for these particular students, was one that those in charge of them were best able to determine. In his opinion the meeting had been

discussing the difference between the education required for two different sets of men, and had not been discussing either of the subjects of the Paper. Further, he particularly desired to call attention to the fact that the ability and education required to enable a man to earn £3 a week, were very different from the ability and education required to enable a man to earn £3,000 a year.

The PRESIDENT, in notifying that the discussion was concluded, said any member who desired could communicate his views in writing on any points raised by the Paper, subject to the right of reply by the author. Professor Worthington had alluded to what he, the President, had on many occasions drawn attention to, namely, that for its own purposes, whether they admitted of universal application or not, the Admiralty had given to this country and the world for fifty years an object lesson in the most perfectly organised scheme of technical education existing anywhere. That was putting in a few words what was a fact. He had amplified his experience on that subject in the Address which he gave to the Institution of Junior Engineers in October of last year, and if anyone wished to know his views on technical education generally, he could turn to that Address. He would only now say that he did not think there were many people who had a much wider experience of technical education than himself, either as student, professor, or examiner. Having ceased to teach in any Institution, he still took a lively interest in the work done by others. His confession of faith was simply this: That for anybody who had to do with the mechanical professions, the very best thing was to take workshop experience at an age when one was capable of receiving the best impressions. The capacity for manual training, the readiness to rough it, was at that age such as could be found at no other age. Having seen the systems of training which prevailed not only in this country but abroad—and there was no more perfectly organised system of education than was to be seen in France—his strong conviction was that the postponement to a more advanced age of actual practical work, was a misfortune to anybody. In saying that he wanted the members to believe that he was the

(The President.)

strongest advocate of scientific training in its highest form. He thought that discussions of technical education often confused two things, the training of the ordinary individual and the training of the man who was to be the director, the initiator, and the manager. He believed in the training of all. He believed that there must be that process of sifting and selection which Professor Unwin referred to. There was no system of education he had ever heard of that was capable of universal application. Individuals differed: thank goodness they did. If all were equal, how deadly dull the world would be. Systems of education could only be pursued on broad lines to suit the conditions of the moment, but to anyone who had studied the half century of successful working—which, thanks to the action of the Admiralty, was now before the world, which had produced men who were taking the lead not merely in the Admiralty service in this country, but in the great industrial shipbuilding and marine engineering establishments—it would be apparent that the Admiralty, by its foresight and generosity, had benefited those two industries in this country to an extent that was little understood. The chief surveyors of Lloyd's Registry and the leading men in some of the most important shipbuilding and engineering industries in the country outside the Admiralty service were Admiralty trained, and when a successful experience of that kind could be pointed to, it was a matter well worth studying by those who wanted to consider how best to adjust the technical education of the country.

Mr. Mayston in reply said it was intended to combine the two subjects for the purpose of seeing what the training of the engineering students was. Professor Unwin had asked if there was any higher training. That had been purposely left out of the Paper, because he was only dealing with the five years during which the students were undergoing practical training in the dockyards. At the expiration of five years a certain number were selected to go to Greenwich, and of that number a few were selected for three terms at Greenwich, and they got the higher appointments subsequently. It was not intended to deal minutely with the machinery of the ships. Had it been so, he did not know to what length the

Paper would have gone. But he might tell Professor Unwin that the Admiralty were now, and had been for some time past, making special experiments in order to determine the amount of fresh water used in connection with the trials in Her Majesty's ships, and if he recollected rightly many of those results had been already published in *Engineering* and *The Engineer*. On all such trials the best Welsh coal was used. Mr. Heath had spoken about the combination of practical and theoretical work, and mentioned the fact that Mr. A. E. Seaton of Hull was throwing himself into work which was of a similar character to that done at Keyham. Seeing that Mr. Seaton was an old Keyham student, and Mr. Heath was also brought up at Keyham, it was not surprising that Keyham ideas had travelled so far north as Hull. The drawing-office instruction was referred to in the Paper (page 386), which stated in the fifth year course that "The remaining five months are spent in the drawing office, learning engine drawing and design, the latter part of the time being occupied in the preparation of a drawing from his own sketches, which drawing is required to be done to enable him to pass into the Navy." The students had also practice in sketching throughout their training, so that the question of drawings was not lost sight of. A member had made a remark as to whether anybody was told off to look exclusively after engineering students. The Admiralty had appointed an engineering officer of very good standing, with long sea experience, who did nothing else but look after those students, acting under the direction of the chief engineer of the dockyard. With regard to the suggestion of the appendix, he did not think he could quite fall in with that, but if any gentleman would like further information and would write to him, he should be exceedingly glad to do what he could to satisfy him.

OUTLET VALVES AT THE BURRATOR RESERVOIR OF THE PLYMOUTH WATER WORKS.

By Mr. EDWARD SANDEMAN, *Member*,
Borough Water Engineer, Plymouth.

Before describing the Valves which form the subject of this short Paper, it may be interesting, particularly to those who may visit the source of the Plymouth water supply, to give a general idea of the works.

History.—In the year 1585 the Corporation obtained an Act of Parliament which gave powers for the construction of a weir across the River Meavy, and for the cutting of a channel or water-course locally known as a leat, from the weir to the town, a distance of 10½ miles in a straight line, but 17 miles along the course taken. That water was urgently required by the town at this time may be gathered from the following quotation from the Act:—"The saide Towne being subject to fyer, as well by the Enemye, for the same was once burned by ffrench in the tyme of warre, as by negligence and other mishappe at Home, there is no water in or nerer the saide Towne for the most Parte of the yere (especially in the Summer Tyme when the Daungers be greateste) then a Myle or sometyme more, as the dryeth is . . . ." The weir and leat were constructed in the year 1591 by Sir Francis Drake, the navigator, and were the means of supplying Plymouth for 300 years.

Reservoir.—The Act, authorising the construction of the reservoir just completed and of the pipe line to supersede the leat, was passed in 1893. The reservoir, which was filled for the first time last winter, is known as the Burrator Reservoir, Fig. 14, Plate 124, and

is situated on the western slope of Dartmoor, about four miles south of Princetown, Fig. 13. It contains 651 million gallons, and the watershed above it is 5,360 acres in extent. The top water-level is 708 feet above the sea. The reservoir is formed by two embankments, one of masonry, 77 feet high, Plate 121, and the other of earth with a puddle core 23 feet in height. The outlet pipes are three in number, laid through the masonry dam, Plate 122, their sizes being 36 inches, 30 inches, and 25 inches respectively, the latter being the diameter of the town's supply main.

Control of Outlet Pipes.—The object of this short Paper is simply to describe the manner in which the outlet pipes are controlled. It should be first premised that the valves within the reservoir were designed with the view of avoiding the usual costly valve-tower, which, in the case under consideration, could not be conveniently introduced into the design of the masonry dam, nor would a separate structure in close proximity to it have been satisfactory. It would have been an easy matter to use sluice valves of the ordinary description on the outlet pipes, but there are objections to the use of these valves in places where they cannot be reached for repairs.

Prominent amongst the methods employed by various engineers for drawing off water from reservoirs is that adopted by Mr. G. F. Deacon at the Vyrnwy Reservoir, which is an extremely simple and efficient method (Proceedings 1891, page 463). The arrangement consists of a series of pipes placed vertically one above another, the lowest pipe being connected with the straining tower and the highest projecting above water-level. By means of hydraulic machinery within the tower one or more pipes may be lifted, leaving an inlet for water at any required level, the shutting off being accomplished by simply lowering the pipe or pipes again.

This admirable arrangement meets the salient points which require consideration in the design of outlet valves. These points may be summarised as follows:—

1. Ability to draw off water at different levels.

2. Reduction to a minimum of the weight of water in opening and closing the valves.

It is well known that great power and strength are necessary in valves which have to be used against a considerable head of water, and especially is this the case when the closing of the valves is in process. At the Burrator water works the largest pipe is estimated to be capable of delivering 200 million gallons per day, and in this instance the force to be reckoned with is equivalent to a weight of 36,000 tons travelling at the rate of 36 miles per hour, or 10 tons travelling 52½ feet per second, and it will be apparent that unless this force is brought to a standstill slowly, a considerable shock must inevitably result. The outlet pipes from the reservoir are provided with valves on the inside as well as on the outside of the masonry dam. On the down-stream side are placed the valves which are for ordinary use. It will be seen from the plan that, with the exception of two, these valves are arranged so as to be in one valve chamber.

The 36-inch and 25-inch pipes, which were laid in the 10-foot outlet tunnel through the dam, divide into four pipes which are respectively 36 inches, 30 inches, and two 25 inches in diameter, Plate 122. The 36-inch and the 25-inch pipe continue directly into the weir pool. These pipes are used in emptying the reservoir. When used in conjunction with the 30-inch pipe at a higher level, the reservoir can be emptied in 2¼ days.

Valves for ordinary use.—There are two valves on each pipe, each of a different kind. That nearest to the reservoir in each case is the ordinary double-faced sluice door with a bye-pass, whilst the second one is a double-spindled valve, having two doors, the smaller of which, being about one-seventh the area of the larger, is intended to be opened first, thereby relieving to some extent the pressure against the larger one. It would probably have been an improvement on these valves had their sectional area been reduced to from one-third to one-half that of the pipe, as on the principle of the Venturi tube the loss of the delivery power of the pipe would not be great.

Special Valves.—These valves were designed to close the bell-mouthed ends of the outlet pipes, in case the valves for ordinary

use required repairs. There are four valves of the type shown in Figs. 9 to 12, Plate 123, and of these it will be sufficient to describe one, the principle being the same, the only difference being in the number of separate lifts in the valves. The largest of the valves, which have been called cone valves from their conical shape, is designed to act upon the open end of a 36-inch pipe, which has a bell-mouth measuring 48 inches across. It is divided into three circular segments faced with gun-metal, Fig. 9. A 3-inch gun-metal spindle runs vertically through the centre of the valve, which is lifted and lowered together with the separate parts of the valve by gearing placed in a chamber at the top of the dam, Fig. 6, Plate 123. Gun-metal rods (and chains passing over pulleys where there is a change of direction) connect the spindle to the gearing, Plate 121.

Action of Valve.—In opening, the upper circular section, which is the smallest, is first raised by the spindle to a height of 4 inches, when it engages the heads of four bolts connecting it to the second section of the valve, and as it continues to rise, this second part also is lifted, rising to a height of 6 inches above the third. By similar means the third section is raised from its seating to a height of 12 inches, so that the valve being fully open leaves three circular spaces through which water can enter the bell-mouth outlet-pipe. In closing, the operation is reversed, the bottom section being lowered first, and the small top section last. All lateral motion of the different parts of the valve is prevented by guides and stays. The total area of the spaces is nearly three times that of the sectional area of the pipe, with the object of considerably reducing the velocity of the water passing through. The action of the four valves at work has been very satisfactory. In the future design of similar valves an air-pipe rising above water-level from the top of each valve might be provided, and for this purpose the vertical spindle might be made hollow.

Water meter.—The water taken from the reservoir for the town's use is measured by a Venturi meter fixed a few yards below the valve house. The pipe on which it is fixed is 25 inches in diameter, which at the throat of the Venturi tube is diminished to $11\frac{3}{16}$ inches.

The meter will measure quantities varying between one million and twelve million gallons, which are recorded on a diagram, and the quantity is also given in gallons by a counter.

Discussion.

On the motion of the President, a vote of thanks was recorded to Mr. Sandeman for his excellent Paper.

Mr. JAMES MANSERGH said he did not propose to say anything about the outlet valves, as he had not seen them himself, although he believed they acted exceedingly well; but, as some of the members were going to visit the works at Burrator, he might say two or three words of general description of the scheme. When he was asked to assist the Corporation in the matter some years ago, he undertook the work with great pleasure, because it was very interesting to be associated with an undertaking which was commenced over three hundred years ago by Admiral Drake. To be in at the finish of a work which he had commenced was very nice to have on one's record. Admiral Drake, as Mr. Sandeman had described, constructed a low weir across the river Meavy, some 8 or 10 feet high, and from that weir carried a leat along Dartmoor down to Plymouth. The leat was an open one, and in course of time as population grew, the pollution was too serious to be borne. Another difficulty occurred very frequently, namely, on Dartmoor in times of heavy winter weather the leat had been covered with 15 to 20 feet of snow, and as there was very little storage at the Plymouth end of the conduit, the town ran a great risk of having its water-supply stopped entirely. In fact on some occasions the military had to be called out to assist in clearing the leat. For those causes the Corporation determined practically to abandon it, and the open conduit has now been replaced by a pipe from Plymouth to Burrator. In 1893 an Act was obtained to construct a reservoir upon the

(Mr. James Mansergh.)
Meavy, to hold about 650 million gallons. The watershed of Dartmoor was exceedingly useful because it was very prolific. The area was 5,360 acres, Fig. 13, Plate 124, and its special usefulness consisted in the fact that the dry-weather flow was exceedingly high. From that 5,360 acres he believed he was right in saying that the lowest discharge had been about three million gallons a day. He might compare that shed with one he was now working on in Radnorshire, in connection with the Birmingham scheme, which had an area of 45,600 acres, eight and a half times the area of the Meavy shed; and on more than one occasion there had been a dry-weather discharge not exceeding four and a half million gallons a day, that was only half as much more from eight and a half times the area. The Meavy shed was therefore an exceedingly valuable one, and but for the special circumstance of its abnormally high dry-weather yield, Plymouth would have had to do the work which they had carried out under the Act of 1893 many years ago. With the increase of population, and the need for additional water, the reservoir was a necessity. There had been some interesting experiences in the carrying out of the work. The reservoir had a very unusual shape, Fig. 14, Plate 124, due to the fact that when the water-level was raised by putting the 80 feet dam across the main stream at Burrator, it would have overflowed a depression at Sheepstor, if a subsidiary dam had not been erected there. The main dam was constructed of masonry, and the smaller one, about 13 feet above the ground level, was constructed of earth, with a concrete tongue below ground and a puddle core above. The trench was a very troublesome one, owing to the presence of numerous faults or fissures in the rock crossing at different angles in plan, and at all sorts of inclinations vertically. Through most of them water passed freely, and they had to be followed down until solid water-tight material was reached. Some of them were filled apparently with the main constituents of granite, out of which the cementing material had disappeared. Others had the appearance of rubble walls jointed with mud. Much of the weak rock passed through was beautifully coloured in various tints, and it would be most instructive if any geological authority could explain what agencies had operated in

bygone times to produce these extraordinary results. To such an authority this question would no doubt be much more interesting than to the engineers, who had to keep piling on a big extra bill, to the disgust of their employers, to ensure this petty little bank being water-tight.

The President asked what was the depth to which the tongues had to go.

Mr. Mansergh said in one place it was necessary to go 105 feet to cut out one of the fissures. In the Burrator dam the fissures always took a wedge-shaped form, beginning about 5 or 6 feet wide, and ending on the solid rock by a black line.

With regard to his position on the work, it had been that of consulting engineer. The real work had been done by Mr. Sandeman, who had submitted the drawings and specifications to him, and which he had been able to return approved with practically no alterations. To Mr. Sandeman was really due the credit of the design and execution of the work. He was glad to have the opportunity of saying that in Plymouth, where he hoped that the author's services would be recognised, as good men like Mr. Sandeman were likely to be taken away from places where they were not properly appreciated. Those members who intended to inspect the works would have the opportunity of seeing a granite wall 300 feet long and about 80 feet high, as nice a little job as could be seen in a week's tramp. Granite was generally considered a hard sort of stuff to work, but in the Elan Valley they were working in the much harder grits and conglomerates of the lower silurian, which were the only materials they had to build their walls with. From the Devon and Cornwall country a number of men were obtained to work this stone, these men being great experts at the plug and feather business, and also at dressing. After nine or ten months they went back home to ease their elbows on the softer granite.

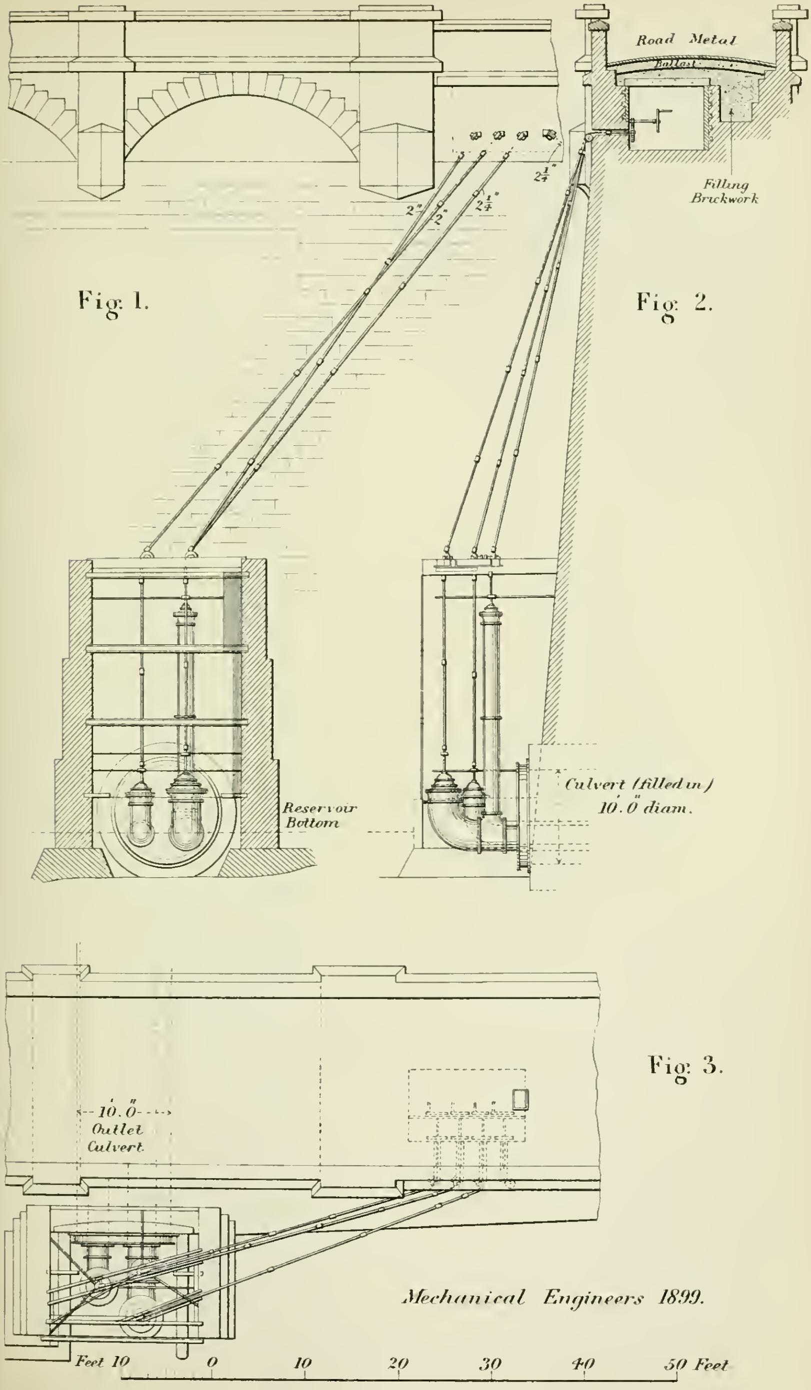
Mr. J. Owden O'Brien asked what was the width of the tongue in the rock.

Mr. SANDEMAN said the width of the concrete was 5 feet, the trench itself being about 7 feet.

Mr. H. W. PEARSON wished to ask one or two questions with reference to the conical valve, Figs. 9 to 12, Plate 123. He asked whether it was thought that at any time there would be seizing in the guides, and whether there would be any difficulty in the gear for lifting them. One could quite understand there was a controlling valve on the other side, but it would be rather awkward if those valves got seized down and shut off altogether. With the ordinary sluice-valves they had in Bristol for many years, there was often a difficulty to know what to do, if the valves became seized down in the outlet from the reservoir. With regard to the Venturi meter, which had come into use during the last few years, he asked Mr. Sandeman if he found its behaviour was what he would have expected, and whether he had any check upon the measurement of the water through it, and with what accuracy he could measure the water. As to the foundations, he had occasion to see Mr. Etheridge, who he thought was concerned about four or five years ago in the matter, and he always understood from him that there was a great difficulty in getting a good foundation. That seemed to have been overcome by Mr. Sandeman and Mr. Mansergh, and the best proof of its having been got over was that the reservoir was perfectly tight.

Mr. WILLIAM INGHAM, Torquay, said that, having been engaged on the Burrator Reservoir Works under Mr. Sandeman for over three years during the earlier part of the work, he should like to ask a question with regard to the valves. The valves were not there before he left the works, but he saw them on the opening day last September, and it struck him at the time that there would be a certain amount of back-lash in the valves. There were three different faces, and those who have had experience in the working of pumping engines knew that where there were several lifts sometimes there was a very hard blow caused, when the water contained air. The rods, which went down from the top of the dam to a point vertically over the valve, were at an

OUTLET VALVES AT BURRATOR RESERVOIR. *Pl. 121.*



OUTLET VALVES AT BURRATOR RESERVOIR.

Outlet Pipes and Valve Chamber.

Fig: 4. *Longitudinal Section.*

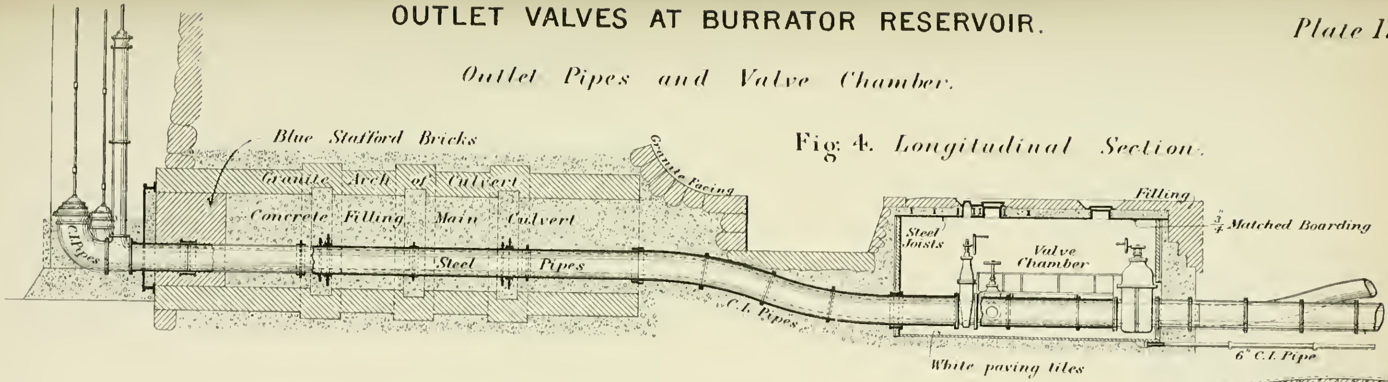


Fig: 5. *Sectional Plan.*

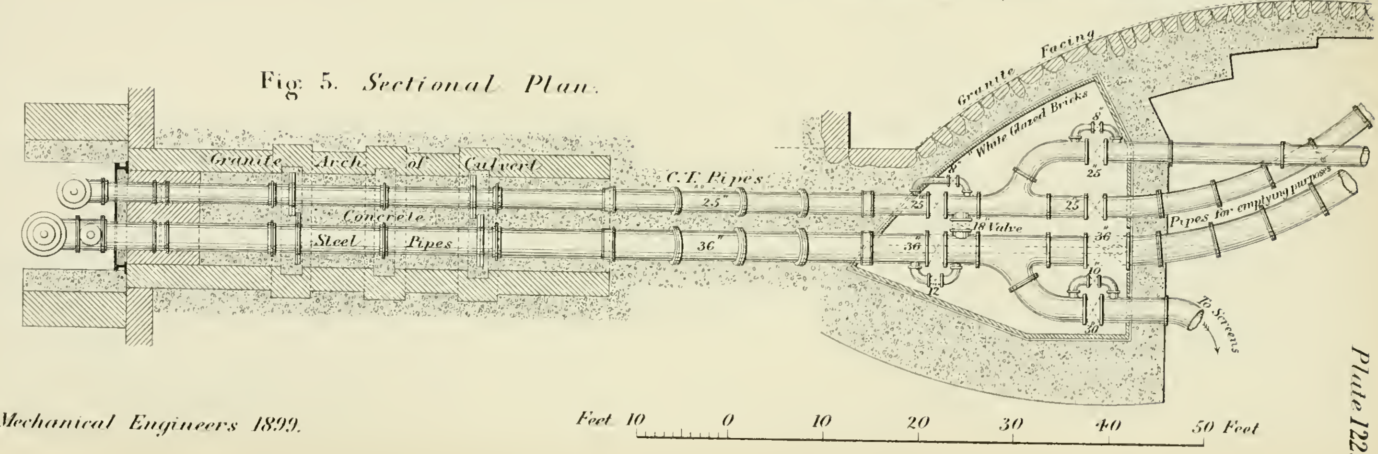


Plate 122.

OUTLET VALVES AT BURRATOR RESERVOIR.

Plate 123.

Gearing for working Cone Valves.

Fig. 6.

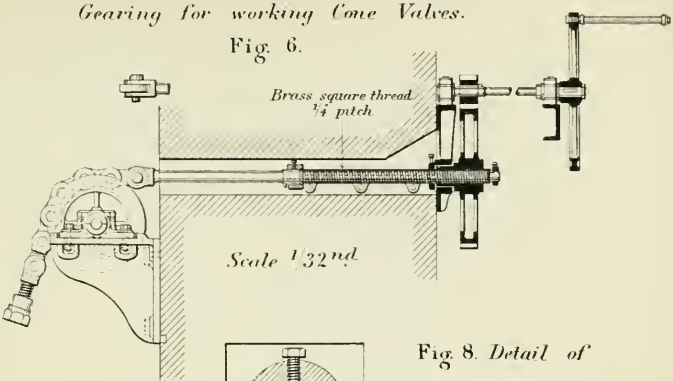
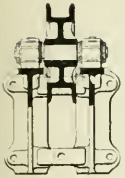


Fig. 7.



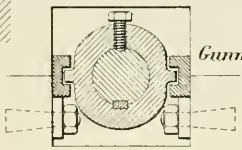


Fig. 8. *Detail of Gunmetal Guide on Screw.*

Scale 1/8th.

36" Cone Valve.

Fig. 9. *Sectional Elevation.*

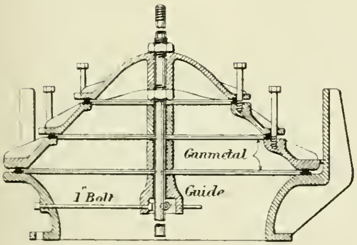


Fig. 10. *Part Plans of Bellmouth and Valve.*

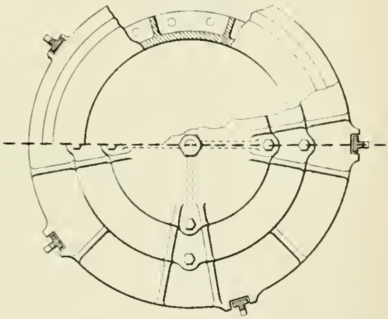


Fig. 11. *Half Plans of Second and Third Rings.*

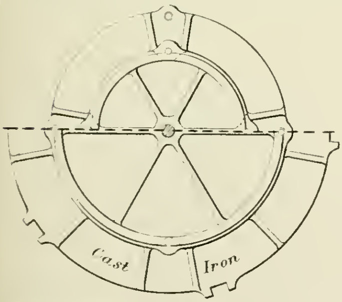
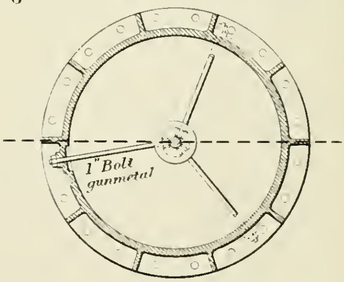


Fig. 12. *Sectional Plan of Bellmouth.*



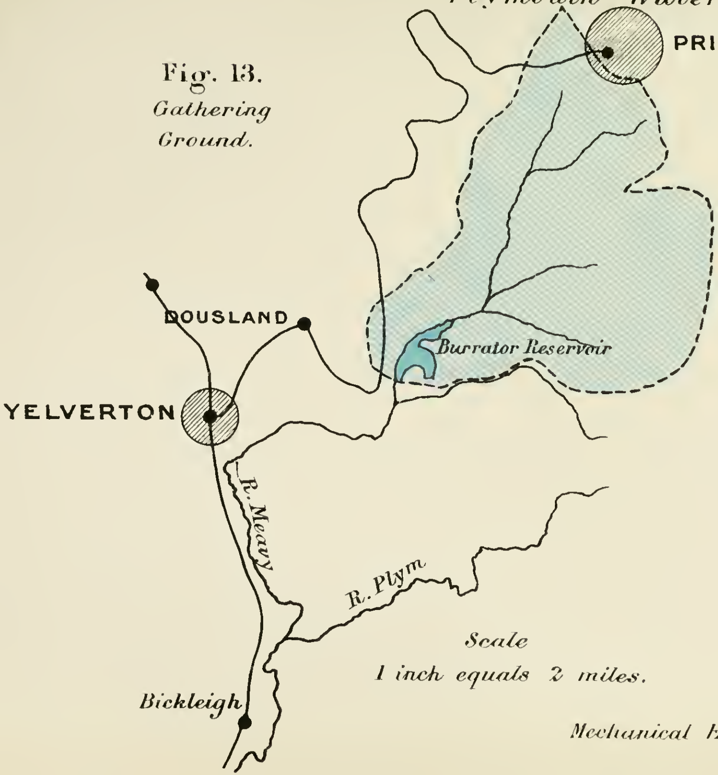
Mechanical Engineers 1899.

Inches 12 0 1 2 3 4 5 6 7 8 *Feet*

OUTLET VALVES AT BURRATOR RESERVOIR.

Plymouth Water Works.

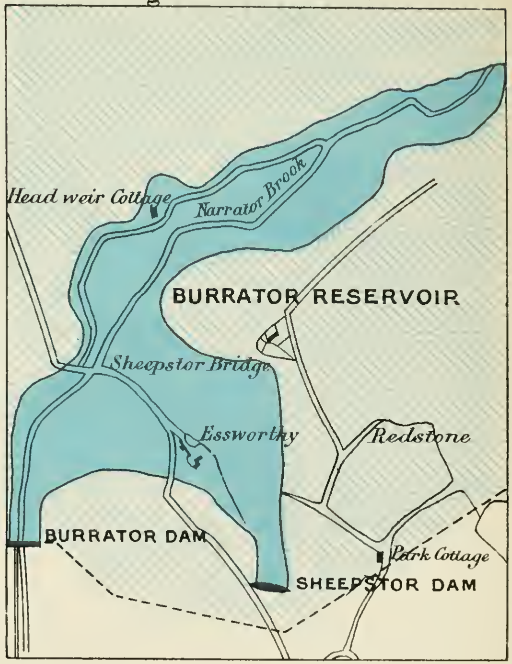
Fig. 13.
Gathering Ground.



Scale
1 inch equals 2 miles.

Capacity of Reservoir 650 millions of gallons.

Fig. 14. *Reservoir.*



Scale 4 inches equal 1 mile

Mechanical Engineers 1899.

Plate 124.

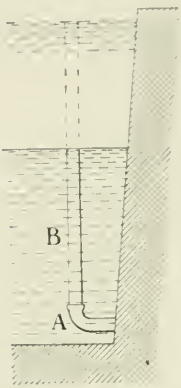
inclination of about 50 degrees, and therefore the rods had a considerable sag. Whether there were any supports to those rods or not he could not say, but he thought if they were left in the condition in which they then were, there would be a certain amount of play in the valves, just when they were perhaps about half an inch off being closed. Perhaps Mr. Sandeman had been able to try the valves several times, and as one of his old assistants, he should like to know whether they had come up to his expectations or not. He was pleased to hear Mr. Mansergh admit that Mr. Sandeman had carried out the works practically by himself, because there was no doubt that the work had been of a very troublesome character, and had given Mr. Sandeman a great amount of anxiety. With regard to the Sheepstor trench, there was considerable difficulty in getting a good foundation. When he said that no less than 500,000 or 600,000 gallons of water found its way into the trench in one day, it would be admitted that it wanted looking after very carefully. Those who had sunk trenches knew very well that if the water was allowed to get above the timbering endless trouble would ensue.

Mr. Henry Davey, Member of Council, said he was sure the members were all very much obliged to Mr. Sandeman for his Paper. The subject was that of a new kind of outlet valve for reservoirs, and they were always instructed by new experience. He did not remember having met with an outlet valve of that description before, but it seemed to be a peculiarly ingenious one for the purpose, and it certainly had avoided the construction of a tower. It was quite obvious that if the outside valves were not apt to go wrong at any time, the inside valves (except for the purpose of drawing off water at different levels) would not be absolutely required. Inside valves were used for the purpose of drawing off water at different levels, and for the purpose of shutting off the water altogether, that the outside valves and pipes might be repaired when necessary. The system of pipe valve mentioned in the Paper might be further described. The pipe valve, Fig. 15, page 416, possessed one peculiar feature. Supposing A represented the outlet pipe from the inside of the reservoir, let the pipe B be dropped from above on to the pipe

(Mr. Henry Davey.)

A, so as to make a water-tight joint, then the water must rise to the top of the pipe B before it can run out, and if the pipe B is made long enough to rise above top-water level, it will answer the same purpose of a stop-valve. The system can be used for drawing off water at different levels by having longer or shorter pipes, or it can be used as a stop-valve by having a pipe which would extend above the water level altogether. The pipe was the valve, and if anything was wrong it could be drawn up and put back again. The valve which Mr. Sandeman had designed was exceedingly ingenious. It was a valve which could not be drawn out for repairs, and he did not see it was easy to contrive any valve that could be drawn out for repairs, unless one went to the expense of a water tower or a structure to contain the pipe-valves just described. He had no doubt the valve which Mr. Sandeman had adopted was one which answered its purpose, but he apprehended that there might be one or two little practical difficulties. He did not say they were of very great moment, because the valve was used for shutting off the water in exceptional cases only. It was not a valve that was in every-day use. But he imagined what would happen when the valve was nearly closed was that the pressure of the water on the valve would cause the valve to take up suddenly the sag of the rods, so that there might be a dithering action on the valve during its closing. He did not point that out as a serious difficulty, but as a mechanical contingency. He asked what was the nature of the cleats, which he imagined were made of gun-metal; and he also wished to know whether Mr. Sandeman had experienced that dithering action in the opening and closing of the valves.

Fig. 15.



Sir Frederick Bramwell, Bart., Past-President, said he had never been able to see why the contrivance used in softening tanks to draw off the water should not be applicable to very deep reservoirs. It was merely a pipe with a float at the top, and the

water could be drawn off at any level desired. The pipe rose or fell with the water, and always drew off just a little below the surface. As regards stopping delivery altogether, all that had to be done was to hoist the pipe up out of the water.

A Member asked why syphons were not used in the case of reservoirs. He supposed that practically speaking a valve under water could not be repaired unless the reservoir was empty.

Mr. Sandeman in reply thanked Mr. Mansergh for his exceedingly kind remarks. With regard to the seizing down of the outer valve, he did not anticipate any difficulty in that direction. There had been none so far, and he did not see exactly why there should be. He was sorry that up to the present he had not had sufficient opportunity for testing the Venturi meter, but the test that was made in the small reservoir containing a million gallons led him to believe that very accurate results, probably correct between 1 and 3 per cent., would be obtainable by the use of the Venturi meter. Mr. Ingham had spoken of the back-lash which might occur in the outward valve. On every occasion except one, the valves, of which there were four, had worked in the most easy and satisfactory way. On the one occasion, from some unexplained cause, there was a small accumulation of air under the top part of the valve, which caused the spindle to bend backwards and forwards. That had never been repeated, and as would be seen in the Paper he suggested that if any of the valves were made in the future, the spindle should be made hollow to allow of that air escaping. Mr. Davey spoke of the dithering action, which he imagined to be a shaking action, but he had not noticed anything of that kind. With regard to Sir Frederick Bramwell's suggestion, that the same means could be adopted as were used for drawing off water in sewage works—

Sir Frederick Bramwell: No; in softening hard water.

Mr. Sandeman thought the same system was also adopted of drawing off the water in sewage tanks—that might very well be

(Mr. Sandeman.)
adapted for drawing off the pure water, but he did not see how it could be applicable, when it was required that the valves should be opened right to the bottom of the reservoir. Regarding the use of syphons, he thought the gentleman who spoke did not realise the depth of the reservoir, which was 77 feet.

Mr. Stephen H. Terry wrote that he felt special interest in this Paper, as he had visited, inspected, and reported on the water-supply of Plymouth in 1883 for the Local Government Board in his capacity of engineering inspector to the Board, and had then traversed the entire route of the Plymouth leat and pipes from the river to the service reservoir. On that occasion he had reported strongly in favour of the complete piping of the leat and the construction of an impounding reservoir. The late Mr. Thomas Hawksley and the present Mr. Charles Hawksley had made careful surveys and reported on the district some twenty years ago, arriving at the conclusion that an impounding reservoir, such as that now constructed was an absolute necessity and must be made without delay. It was therefore a matter of satisfaction that so fine a reservoir as that at Burrator had now been formed.

REFUSE DISPOSAL, AND THE RESULTS OBTAINED FROM A SIX MONTHS' WORKING OF THE REFUSE DESTRUCTOR AT TORQUAY.

By Mr. HENRY A. GARRETT,
Borough Engineer and Surveyor, Torquay.

In the preparation of this Paper upon "Refuse Disposal" it is not the author's intention to repeat information and statistics obtained during a long period of years, nor to quote from published reports more than necessary, but merely to touch very briefly upon one or two important points connected with Refuse Disposal, and then to record his actual experience upon the first six months' work of the Torquay Refuse Destructor.

Many recent reports and tests upon "Destructors" by eminent men, whose names include Sir Douglas Fox and Lord Kelvin, made the author at first doubtful whether the information he had gathered would be of value: but as these tests have been made by direct instruction of the Town Council's Destructor Committee, the author came to the conclusion that he might venture to give his brethren in the profession the benefit of his experience.

It is now almost universally acknowledged that the only satisfactory method of disposing of towns' refuse without nuisance or danger of infection is by cremation in suitable furnaces or cells; and by the introduction of modern mechanical inventions the heat generated by the combustion of the refuse may be turned to a useful and profitable account.

Since the introduction of the first modern destructor about the year 1876 rapid progress and improvements have been made in their design, and many different forms of destructors have been invented.

The engineering profession has been inundated with literature containing statistics, information, and reports upon various systems, each and all severally claiming to be more or less in advance of its rival.

Combined schemes of refuse destruction and electric lighting are at the present time receiving a large amount of public attention. Such systems are fascinating, and town authorities, unless very cautious, are sometimes apt to assume that in their towns' refuse they have all the means of obtaining their electric light for practically nothing.

As the power derived from a destructor depends somewhat upon the quality of the refuse available according to each season of the year, care must be exercised not to place too much reliance upon evaporative or combustion results obtained by one or two tests, taken possibly during some most favourable seasons of the year, that is, during autumn or winter months, as is so often the case. It is generally acknowledged that towns' refuse is then of better quality, and naturally contains a larger amount of combustible material of a higher calorific value. With regard also to "combustion" tests or the rate of combustion per cell per hour, results vary according to the quality of the refuse burnt, and in this respect also towns' refuse varies according to the locality. For example, in a residential district like Torquay, where coal and coke are expensive items as compared with any town in the Midlands, there is little waste, the refuse being, as will be seen by the analysis (page 424), largely made up of vegetable and garden refuse, waste paper, straw and packing material mixed with fine dust or siftings, all of light nature, poor quality, and of somewhat low calorific value.

Primary Object of Destructor.—The primary object of a destructor is to dispose of towns' refuse at the cheapest possible cost, and nothing should interfere with the complete combustion of the refuse and its gases. The utilisation of the waste heat must not be obtained in a manner that will in any way interfere with the proper burning of the refuse, nor must the ordinary disposition of the refuse in the destructor be interfered with.

Opinions differ upon the question of temperature in the combustion chambers of a destructor, some preferring those of the highest possible temperature whilst others prefer destructors of slow combustion. From information the author has gathered and which is confirmed by other engineers, the highest temperature destructors cost more for working and considerably more for repairs, and from experience he has found that the slower the combustion the better is the result to be obtained.

Types.—It is generally acknowledged that there are now four recognised types of destructors, namely, "The Fryer," "The Beaman," "The Horsfall" and the "Warner Perfectus," and it is the author's opinion that they are all practically equal in three important things, namely :—

(1) Each will burn refuse without nuisance.

(2) Each will produce the same temperature.

(3) Each will generate the same quantity of steam with the same class of refuse.

With regard to the cost of working and of burning the refuse per ton, some of the destructor works where systems referred to above are in operation take simply the cost of the stokers, but on close inspection it will be found that there is generally an odd man about the works whose wages are charged to another account; then there is the foreman of the refuse disposal department and possibly a weigh clerk, who are also charged to another account, but whose wages (if not the whole at any rate part) should be included in order to arrive at the true cost.

This method of taking out the cost appears to the author to be general and more pronounced where tests are made for advertising purposes, and where those in charge are interested in obtaining good results.

If these points were more carefully observed and care taken to include *all* wages, more reliable information would be forthcoming, and local authorities and those advising them upon the best system to be adopted would receive material assistance therefrom.

Cost of Treatment of Refuse.—Upon the question of cost of treatment of refuse, and referring to some of the most recent reports, it will be found that at Edinburgh it is given at 1*s.* 7*d.* per ton, yet at Oldham and Bradford, where they have practically the same destructor as at Edinburgh, the cost is given at 7*d.* and 6*d.* per ton. It is difficult to reconcile these figures. The author is however inclined to take the figures given at Edinburgh as being reliable. The average of the cost of treatment at Edinburgh, Oldham, and Bradford is over $10\frac{1}{2}$*d.* per ton. The "Beaman" at Leyton and Dewsbury deals with refuse at an average cost of 1*s.* 5*d.* per ton. The "Fryer" at Liverpool appears to do better, and the cost is given at 1*s.* per ton, and the "Fryer" at Bournemouth 11*d.* per ton. With regard to the latest "Warner Perfectus," erected at Torquay, and now in the charge of the author, the cost under conditions referred to in Test No. 1 (page 425), was a fraction under $9\frac{1}{4}$*d.* per ton, and a fraction over 6*d.* per ton under conditions of Test No. 4 (page 427).

Although these figures show that the "Perfectus" destructor at Torquay is able to deal with the refuse at such a low cost, the author does not think that, when all destructors are treating the same class of refuse at the same wages, there is much to choose between the latest high-temperature types of the "Perfectus" and the "Fryer."

Torquay Destructor.—The destructor is one of Messrs. Goddard, Massey, and Warner's latest types, Plates 125 to 128, comprising four cells back to back, having each about 26 superficial feet of fire-bars, of the rocking type upon the wedge-shaped principle. At the back of the fire-bars directly under the hoppers is a fire-brick drying hearth with a reverberatory arch built over so as to reverberate the heat upon the newly-fed refuse on the hearth, thus partially drying it before it reaches the fire. Two multitubular boilers are built in between the cells, the shells of which are 3 feet diameter by 12 feet 3 inches long with steam drum 3 feet diameter by 9 feet long, and each is set at a working pressure of 80 lbs., but tested up to 300 lbs. upon the square inch. There are two engines, one horizontal, having a steam cylinder 10 inches

by 20 inches stroke, and one vertical engine with steam cylinder 6 inches diameter.

The horizontal engine is used for driving a heavy mortar mill, Fig. 2, Plate 125, having a pan 7 feet diameter, and a Warner's clinker mill, also for driving a dynamo for lighting the works and the district in the immediate vicinity of the destructor. The vertical engine is used for driving the high-pressure fan, by which air is drawn through an 18-inch iron-pipe from over the top of the tipping platform, so that the foul air from the refuse may be extracted from the main building and passed under the fire-bars.

An oil-jet cremator has been provided in the main flue, but this has not yet been made use of, as the temperature in the cells has been found sufficient to consume without nuisance all the refuse delivered to the destructor.

The circular chimney shaft, constructed of red brick and surmounted by a cast-iron cap, rises to a height of 150 feet above the ground line and rests upon a solid bed of concrete 25 feet 6 inches square, 12 feet thick, carried down to a depth of 19 feet below the ground-level. In addition to being used in connection with the destructor, a 15-inch pipe from the main line sewer in the immediate vicinity has been brought to and connected to the cremator chamber. The shaft thus acts as a sewer ventilating column. The shaft is lined with fire-brick to a height of 50 feet. At the base of the shaft is constructed a special dust-catching chamber, which prevents the possibility of any dust being carried out at the top of the shaft. A mess room and bath room for the men are also provided, together with an office store and weighbridge at the main entrance.

The whole of the works are enclosed in a substantial building constructed of uncoursed limestone masonry, and are situated in the centre of an apple orchard. The locality is thickly populated on one side, and has a large area of building land on the other side, which is now being rapidly built over. The whole cost of the works, exclusive of the land, has amounted to £6,500.

Owing to the configuration of the district of Torquay, and the site selected being surrounded by hills upon which valuable property exists, the contractors were bound by very stringent

conditions that the destructor should do the work claimed for it without nuisance. The tests tabulated (pages 425–427), were made with a view not only to ascertain whether the destructor was capable of performing the work claimed for it, but, in addition, whether it is possible to extend its utility for electric-lighting purposes outside the works, and they were made quite independently of the manufacturers.

Before the tests were made, the component parts of the refuse of the Borough were carefully ascertained. For the December and January tests, from a total weight of 37 tons 7 cwt. 1 qr. 21 lbs., the refuse was found to be composed of the following:—

(1) Paper, card-board boxes, straw, packing material, and similar matter, 4 tons 12 cwt., or 12·29 per cent.

(2) Vegetable and garden refuse, impregnated with fine ash, 19 tons 10 cwt., or 52·072 per cent.

(3) Screenings, cinders, clinkers, pieces of small coal, and similar matter, 2 tons 8 cwt. 3 qrs., or 6·51 per cent.

(4) Fine ashes and dust, 9 tons 10 cwt. 1 qr. 7 lbs., or 25·423 per cent.

(5) Pots, pans, crockery, bottles and the like, 1 ton 3 cwt. 3 qrs., or 3·172 per cent.

(6) Rags, bones, &c., 2 cwt. 2 qrs. 14 lbs., or 0·3506 per cent.

The component parts of the refuse for the June test, from a sample of about 16 cubic yards weighing 8 tons, being of such an extraordinary nature, were more carefully sorted, and the result was as follows:—

	Cwt.	qrs.	lbs.		Cwt.	qrs.	lbs.
Fish offal	3	2	21	Garden prunings . .	4	1	0
Meat and poultry offal .	0	3	17	Bones	0	1	5
Waste bread, bits of cake	0	1	15	Pots	1	2	4
Brickbats, stones . . .	0	2	3	Bottles and glass. . .	1	3	18
Bits of wood, old boxes .	0	0	23	Straw	1	1	8
Old tins, pans, pails . .	3	2	9	Waste paper	3	2	17
Bits of old iron . . .	1	1	0	Rags	0	0	17
Vegetable refuse . . .	11	3	9	Bits of canvas . . .	1	1	7

	cwts.	qrs.	lbs.		cwts.	qrs.	lbs.
Old boots and shoes	0	0	11	Bits of coal	0	2	17
Fine dust	77	0	0	Bits of coke	0	0	21
Screenings	45	2	0				

Test No. 1, 21*st December* 1898.

Number and type of furnaces	Four "Warner Perfectus."
Number and position of boilers	Two, between the furnaces.
Nature of refuse burned	Unscreened ashpit refuse, very dry and containing a large quantity of waste paper, straw, and packing paper. The first four loads delivered being very light were absolutely destroyed in the first hour and a quarter.
State of weather	Very fine and dry.
Duration of test	12 hours, 8.30 a.m. to 8.30 p.m.
Number of men engaged	Three in addition to half-time of contractor's representative superintending running of the machinery.
Wages of men	12*s.* 8*d.*, including above.
Total weight of refuse delivered to destructor during the day	19 tons 7 cwt.
Total weight of refuse burned during the 12 hours	16 tons 7 cwt. = 36,624 lbs.
Cost of burning per ton	9·29*d.*
Colour of smoke from chimney	First observation 9.30 a.m. light brown. 2.20 p.m. almost colourless, and at 4.0 p.m. light brown.
Total quantity of water evaporated. Starting at 8 a.m. from a cold-water feed and steam gauge standing at 00	1,224 gallons—12,240 lbs.
Refuse burned per pound of water evaporated under disadvantageous conditions above referred to	2·99 lbs.
Average steam-pressure maintained during 12 hours in each boiler (31 readings)	57 lbs.
Highest reading 11.30 a.m.	105 lbs.
Lowest reading 8.0 p.m.	38 lbs.
Total I.H.P. per hour developed, allowing 20 lbs. of water evaporated per I.H.P.	51 indicated horse-power.

Residuals from total quantity of refuse delivered and burned, including that left on completion of test:—

	Tons	cwts.	qrs.
Clinker	2	14	0
Fine ash	0	16	2
Old tins and the like	0	2	3
Total	3	13	1

Percentage of Residuals . . . . 18·93

Test No. 2, 28*th December* 1898.

Duration of test	$3\frac{1}{2}$ hours, 9.30 a.m. to 1 p.m.
State of weather	Very stormy at start, heavy rain.
Nature of refuse	Unscreened ashpit refuse of somewhat better quality than that of December 21st, and containing a fairer proportion of cinders, mixed however with a large quantity of waste paper and packing paper of little calorific value.
Total quantity actually burned . .	3 tons 6 cwt. 2 qrs. 24 lbs. = 7,472 lbs.
Steam pressure in boilers at start .	20 lbs.
Water evaporated from a cold-water feed	350 gallons—3,500 lbs.
Temperature of feed-water . . .	50° Fahr.
Quantity of refuse burned per pound of water evaporated	2·135 lbs.
Average steam-pressure maintained in each boiler	54 lbs.
Conditions under which that pressure was maintained	Steam-jet to oil cremator in use. Vertical engine for fan, 25 horse-power engine, running mortar mill with *exhaust open* whole time.
Total I.H.P. per hour developed after allowing, say, 30 minutes for raising steam	$58\frac{1}{2}$ indicated horse-power.

The third test, of three hours' duration, was made under somewhat different circumstances, namely, after the cells had been raised to a high temperature, and then the heat from the subsequent three hours' combustion was sent continuously through the boilers, careful observations being made of the quantity of refuse consumed and the water evaporated.

Test No. 3, 2*nd January* 1899.

Duration of test.	3 hours, 1.45 p.m. to 4.45 p.m.
State of weather during test . . .	Stormy.
Nature of refuse	Unscreened ashpit refuse, similar to the above, very wet, and containing a larger quantity of cinders, bits of coal and coke.
Total quantity burned	2 tons 5 cwt. 1 qr. 8 lbs. = 5,076 lbs.
Steam-pressure in boilers at start. .	70 lbs.
Water evaporated	300 gallons—3,000 lbs.
Temperature of feed-water . . .	56° Fahr.

Test No. 3 (*continued*).

Quantity of refuse burned per pound of water evaporated	1·692 lbs.
Average steam-pressure maintained during the three hours (average of ten readings)	81·2 lbs.
Conditions under which steam-pressure was maintained . . .	Steam-jet to oil cremator in use; also vertical and horizontal engines in use, with exhaust full open.
Total I.H.P. maintained as in No. 1 Test	50 indicated horse-power.

The fourth test from a sample of the refuse referred to on page 424, made for the purpose of ascertaining quantity consumed per cell per hour with power developed, was as follows:—

Test No. 4, 2*nd June* 1899.

Duration of test.	3 hours, 2.30 p.m. to 5.30 p.m.
State of weather	Very fine.
Nature of refuse	As tabulated on page 424, very light.
Number of men engaged, and wages .	Three at 3*s.* 4*d.* a day of 12 hours, (7 days a week). Wages of superintendent and man running machinery and mortar making not taken into account, as revenue from mortar made and sold is sufficient to cover wages.
Total quantity of refuse actually consumed in the three hours . .	5 tons 0 cwt. 2 qrs. = 11,256 lbs.
Quantity of refuse consumed per cell per hour	938 lbs. per cell, or at the rate of upwards of ten tons per cell per day of 24 hours.
Cost of burning per ton on above basis	A fraction over 6*d.* per ton.
Steam-pressure on boilers at start .	55 lbs.
Average steam-pressure maintained during the whole of the three hours, with both engines running whole time, average of ten readings	52 lbs.
Water evaporated from a cold-water feed	3,080 lbs.
Total I.H.P. per hour developed, allowing 20 lbs. of water evaporated per I.H.P.	51 indicated horse-power.

In comparing these tests it is interesting to note that, although the refuse was of such a variable nature, the power developed on each occasion was practically the same.

These tests having shown that the destructor was capable of developing more power than required for the machinery introduced in its original construction, the Council were recommended by the author to extend the electrical installation by the introduction of a larger dynamo with a battery of accumulators for the purpose of lighting a considerable length of public roads in the immediate vicinity of the destructor. The recommendation was agreed to; and with the able assistance of his colleague the electrical engineer, Mr. P. Storey, the extensions which comprise the following works are now in course of construction, and will be completed in a few weeks:—A nine-kilowatt shunt wound "Taunton Dynamo"; one set of 55 "R" type chloride accumulators with a capacity of 450 ampère hours; a 50-ampère switchboard with ammeter and voltmeter six-way charge and discharge switches, automatic cut-in and cut-out, four circuit switches, ammeter switch and voltmeter key.

The existing street gas-lamp columns are being fitted with a specially designed double arm, to each of which are affixed two 8 candle-power glow-lamps. The number of columns to be converted for the present is twelve,* and in the works there are twenty 8 candle-power glow-lamps and three 1,200 candle-power arc-lamps.

The residuum from the destructor has been analysed by Dr. Bernard Dyer, of London, with the result as shown in the Table on the following page.

A ready sale for all mortar made, clinkers, ashes, and flue-dust, has been effected amongst local builders and others, and a considerable revenue derived therefrom. It is now proposed to manufacture disinfectant powder from the flue-dust by adding crude carbolic acid in sufficient proportion to convert it into a thick paste, and then when

* Since this Paper was written this work has been completed, and with all lamps alight there still remains a sufficient margin to supply current to an additional twenty lamps, which will be converted at an early date.

Residuum from Destructor.

	Ground Clinker.	Flue Dust.
Moisture, organic matter, and water of combination	1·00	6·52
*Phosphoric Acid	1·06	0·96
Lime	10·47	8·40
Oxide of Iron and Alumina	33·54	33·34
Carbonic Acid, &c.	4·41	10·38
Silicious matter	49·52	40·40
	100·00	100·00
Nitrogen . . . . practically none		0·17
*Equal to Ammonia		0·21
Equal to Tribasic Phosphate of Lime . .	2·31	2·09

dry to regrind it in the mortar pan, supplying it afterwards to the men collecting the refuse for use in sprinkling offensive ash-pits or boxes.

In concluding this Paper the author desires to thank the Council for permitting him to prepare and read it. The subject is one of immense importance to local authorities. A record of actual experience in the work of a destructor under ordinary conditions may generally be found to be of value to those who have the responsibility of preparing schemes for refuse disposal, and therefore it has given the author great pleasure in recording his experience in this form.

Discussion.

The President said he had pleasure in moving that the thanks of the members should be given to Mr. Garrett. The Paper had been read in abstract, and many statements of facts omitted, and therefore he invited Mr. Garrett to supplement it by any remarks he would like to make.

Mr. Garrett did not think there was anything he could add to the abstract which had been read by the Secretary; probably if he had read it himself he should have cut out considerably more than had been done. He thanked the President and the members for their kindness in allowing him, a non-member, to prepare the Paper. That was a fault that he hoped would very shortly be remedied. The subject was one which he feared fell very flat after the two days of excellent papers that had been read. It was a subject however which mechanical engineers at the present moment were being called upon to express their opinions about, and local authorities all over the country were considering the desirability of introducing suitable machinery, and so make use of the latent heat which might be found in towns' refuse. He had had considerable experience during the last few years in the work of a destructor. He was one of those who did not believe in the first instance that towns' refuse was of the value that some claimed for it; but he had proved by experience that refuse was of value, and he had given the result of that experience.

Mr. Henry Davey, Member of Council, thought the author of the Paper had been a little modest in depreciating the subject, because it was a most important question and one about which all sorts of exaggerated statements had been made. He remembered when destructors were first proposed, that towns were to be lighted up entirely by the combustion of towns' refuse, electricity was to be generated, and no coal would have to be bought at all. He thought that notion had entirely vanished from the minds of engineers, and

Fig. 1. *Destructor Cells and Boiler.*

Fig. 2. *Mortar and Clinker Mills, and Tipping Platform.*

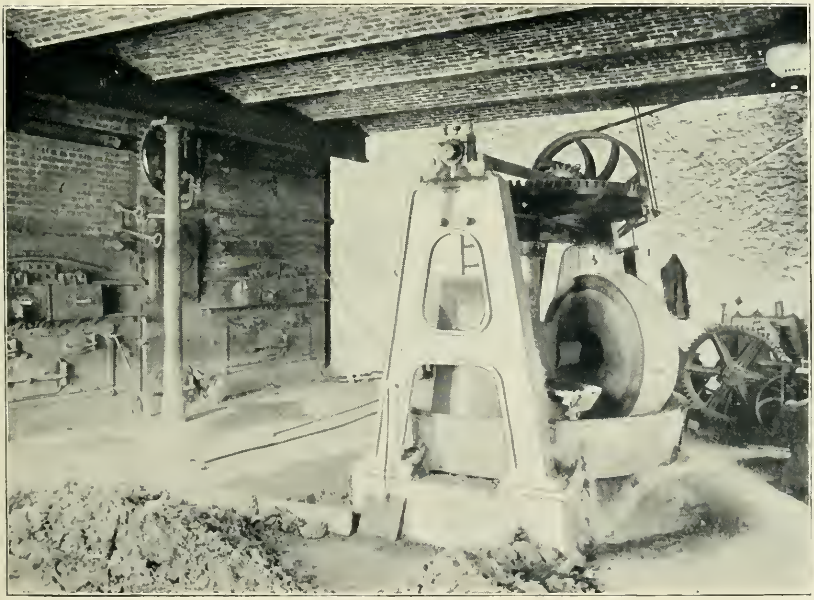
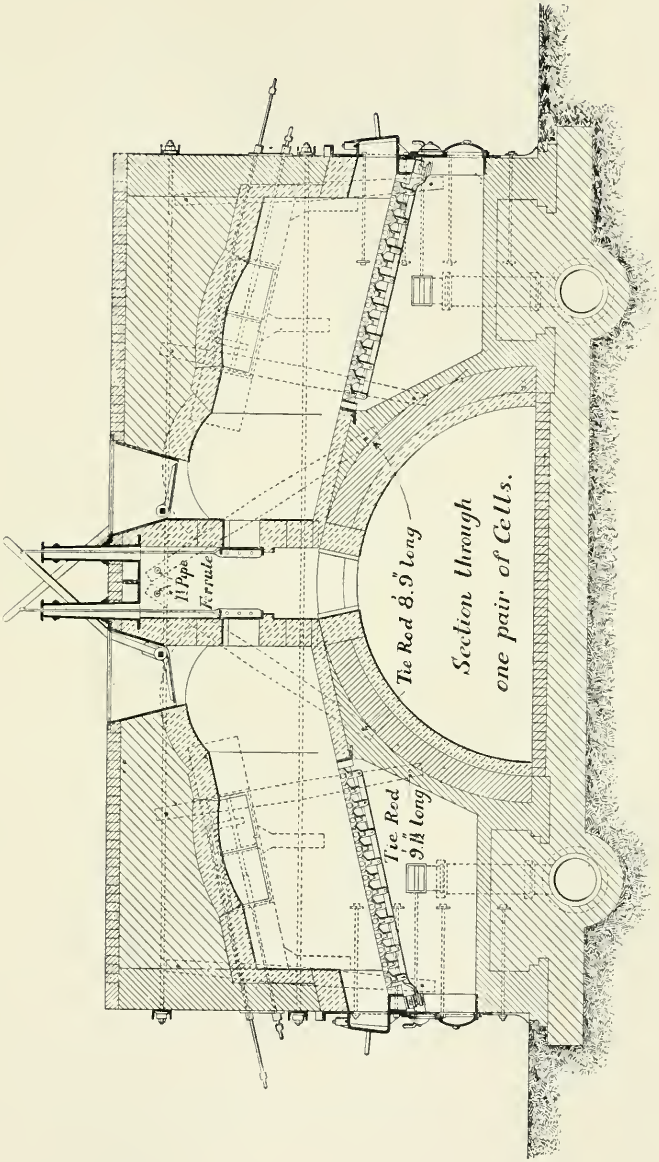


Fig. 3. *Four-Celled Refuse Destructor with two Boilers.*



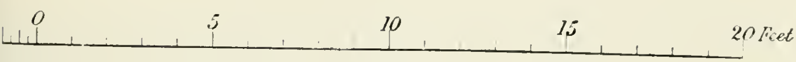
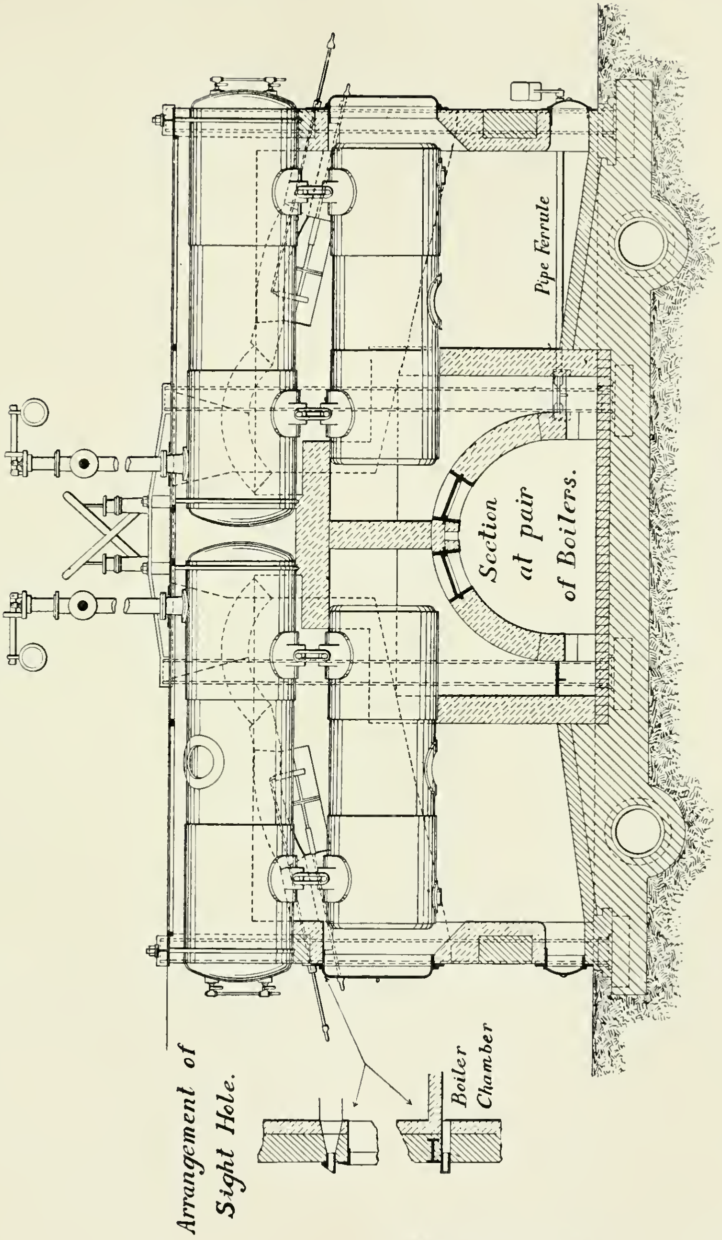


Fig. 4. Four-Celled Refuse Destructor with two Boilers.



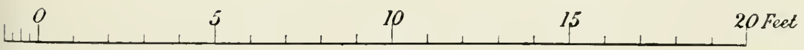
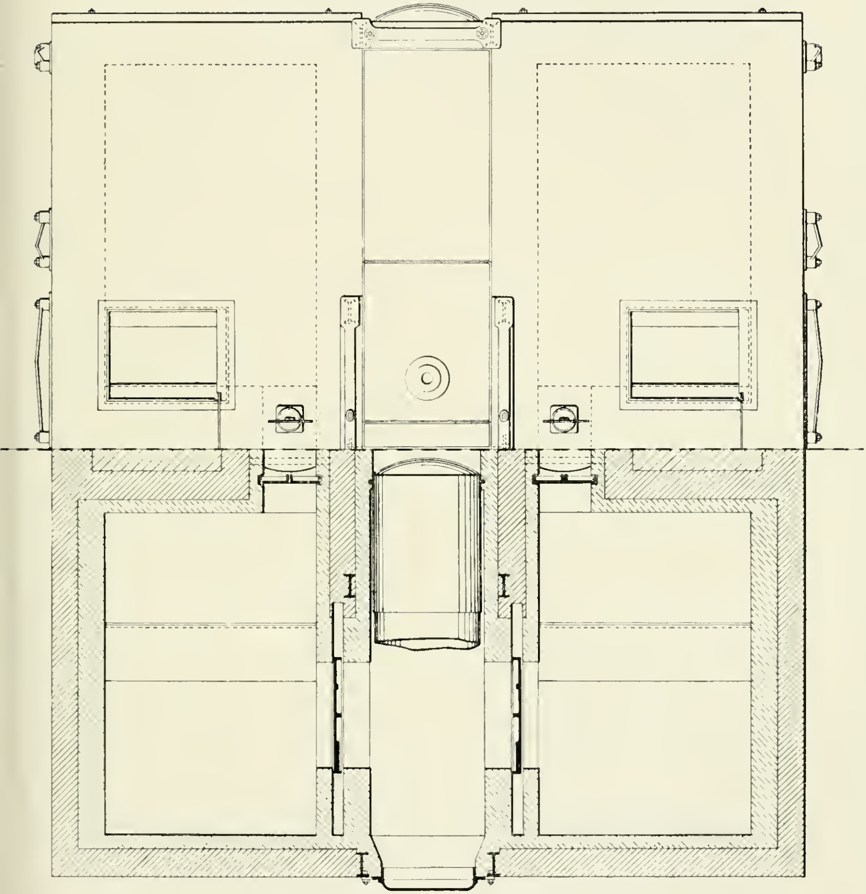


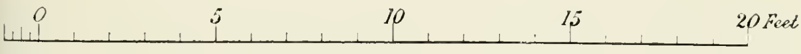
Fig. 5.

Four-Celled Refuse Destructor with two Boilers.

Half Plan.



Half Sectional Plan.



it seemed to him now, that the subject resolved itself into two main questions. First, was towns' refuse of any value as a fuel to a private individual—would any private individual buy towns' refuse or take it if it were given to him, and put up the necessary boilers and apparatus for burning it for the sake of getting the steam? He thought he would find it more profitable to buy coal, even at a high price. If that was found to be so, it disposed of the question as to the value of towns' refuse as a fuel. Then there was another question. Was burning refuse and getting steam from it a cheap and satisfactory way of getting rid of something that had to be got rid of? It might be that when capital expenditure and all the other incidentals had been debited, and credit had been given for the steam obtained from the boilers, that after all it might be the cheapest method of getting rid of something which had to be got rid of in this or in some other way. What were the other methods of getting rid of it? One method was to find a suitable place of deposit into which it might be tipped. If deposited it might create a nuisance. There were other ways of getting rid of it before the destructors were used. The great question to his mind was whether it was the cheapest and best method of getting rid of towns' refuse; and perhaps the author would give a little more information on that question when he came to reply.

Mr. Stephen H. Terry said that, having devoted a considerable amount of time and attention to the design and working of destructors during the past fifteen years, he took an active part in promoting their use during his career at the Local Government Board, because he had always felt that the question of the disposal of towns' refuse was of great importance, both in regard to the health of the town itself and to the reputation—fair or otherwise—of the local authority in dealing with such refuse. He could not think it was a desirable plan to send it out to sea, except such refuse as was sure to sink, and then it was necessary that great care should be exercised in selecting a suitable dumping site, so that trawling and drift-net fishing were not injured, and great vigilance to see that the site selected was adhered to. Refuse that would float

(Mr. Stephen H. Terry.)
was liable to come back again, or it might go to neighbouring seaports or bathing places and create a nuisance. With a material which was capable of producing sufficient heat to pay almost for its own destruction, it was surely better to use it in that way than to allow it to accumulate in heaps, or to send it long distances away. He thought therefore the question was one which concerned not only the largest cities in the kingdom, but even towns of quite moderate size. He felt convinced from the researches he had made in the working of destructors at numerous towns, including Leicester, Cambridge, Shoreditch, and Brighton, that destructors could be worked without nuisance, provided they were properly designed and properly located. If attention was paid to the prevailing winds and to altitude in selecting a site, he was convinced they could be designed and constructed in such a way as to be practically no nuisance whatever to the town whose refuse they destroyed, or to the district in which they were situated. The points to consider were the complete and immediate destruction of all the dust collected, so that there should be no accumulation of refuse at the destructor. Often enough a destructor got a bad name from the fact that the refuse was not immediately destroyed the moment it was collected. It was very important that the refuse should go straight from the dust cart into the charging cells. By the mechanical aid of fans or other appliances the supply of air should be controlled to the exact volume required for combustion. This could not be done by chimney draught alone, because the chimney would give most draught on a day when there was a high barometer and low thermometer. Some form of forced draught was better, because it enabled the supply of air to be controlled, and no more air need be supplied than was just sufficient. Another point to be considered was the proper cremation of the fumes. In a town coming within his experience he had found that £600 a year was being spent in coke simply to cremate the fumes going from the destructor. By obtaining complete combustion by the aid of forced draught he considered that this amount of expenditure or half of it could be avoided, because higher temperatures of combustion would then be obtained. It was also important to make the dust produced by the combustion settle, which could be done by using a scheme somewhat similar to trapping water in steam

pipes by water separators. One could make use of the centrifugal force engendered, by causing the air to circle round curved arches in the brickwork, in which case the dust would touch and eventually settle near the base of the outer of the two concentric walls. To trust to screens alone he thought was of very little use. By a judicious arrangement of catchpits and deflectors fine dust could be made to fall down into bins, and having once fallen below the main current of air it would not rise up again. If all those points were attended to, he considered destructors would be of the greatest use in relieving the expenses which were now incidental to the removal of dust to places outside of towns. With proper combustion a sufficient supply of steam would be available, not only for doing the work required in connection with the destructor itself, as clinker breaking, mortar mixing, &c., but for giving a considerable amount of electric lighting in the neighbourhood of the destructor, supplementing the town supply, and in some cases forming the nucleus of an installation in a town as yet unlighted by electricity. He would like to express his thanks to Mr. Garrett for his most valuable Paper, and also to call the attention of the meeting to the destructor at Brighton designed by Mr. F. J. C. May, the borough engineer. This destructor had already saved the ratepayers many thousands of pounds hitherto paid for transport of the dust elsewhere. It had many points of importance, amongst others the complete separation and isolation of the containing buildings from the destructor proper, thus avoiding any damage to the brickwork of the building from damp and heat, and consequent expansion. In his opinion the Brighton destructor was one of the best in the kingdom, and when certain recommendations recently adopted by the Corporation had been carried out it would be still more economical and efficient.

The PRESIDENT said the time had come when the discussion must cease, but he trusted that there would be sent to the Secretary in writing the views of those gentlemen who were competent to express an opinion upon the points raised in the Paper, and Mr. Garrett would then be given an opportunity of commenting upon the communication.

Mr. R. B. HODGSON wrote that, owing to the short time Mr. Garrett's Paper had been in his possession, any observations thereon could not be so complete or detailed as he would have wished, but he desired to make the following observations on his own experience with destructors and refuse cremation. Firstly, the power derived from a destructor depends not only upon the quality of the refuse available, but also largely upon the construction of the cells, the working temperature, and the steam-pressure, as shown from results obtained with various destructors. Secondly, with regard to the author's remarks about the utilization of waste heat, if complete combustion was obtained in the cells and combustion chambers, while maintaining there a temperature in excess of that required to destroy all noxious matter, he found it did not matter how much heat was taken out of the gases and utilized, as these could not again become foul. Thirdly, it did not follow that because a high temperature was maintained in the cells and combustion chambers, the wear and tear must necessarily be larger than where comparatively low temperatures were used. He could instance cases of high temperature destructors which had been continuously at work for two years and upwards, requiring no repairs whatever, and which did not yet show any signs of requiring repair in the near future. Fourthly, were we to understand that the oil-jet cremator described on page 423 was situated between the cells and the boilers, or between the boilers and the stack? If the former, was it not probable that the oil and not the refuse would do the bulk of the steam-raising? and if the latter, was it not in the wrong place, its object being to ensure that the whole of the gases reached a sufficiently high temperature to destroy all noxious fumes, which could more easily be done when the gases left the combustion chamber at a comparatively high temperature, than when they left the boiler at a comparatively low one? Fifthly, from the tests given it appeared that with screened refuse one lb. of refuse evaporated in No. 1 test, without oil cremator, 0·34 lb. of water, No. 2 test, with cremator, 0·46 lb. of water, and in No. 3 test, with cremator, 0·59 lb. of water. One pound of refuse therefore evaporated on an average 0·46 lb. of water. The writer wished to compare this with what he had seen in the north

and west of England, with refuse making 36 per cent. of clinker as against 18·93 per cent. of clinker at Torquay, where, with no cremator nor added fuel, 1 lb. of unscreened refuse evaporated from 1·34 to 1·64 lbs. of water, or three times as much water per lb. of refuse as at Torquay. It would also be interesting to know both the temperature of the gases, before entering the cremator, and the percentage of CO_2 in the chimney gases. In the cases he had referred to, the temperature of gases leaving the combustion chambers was 2,000° Fahr., and the percentage of CO_2 varied from 15·9 to 16·8 per cent. Sixthly, the I.H.P. in the tests appeared very regular, and the steam-pressure varied between 38 lbs. and 105 lbs. He wished to ask if this was based upon the assumption that 20 lbs. of steam at any pressure between 38 and 105 lbs. per square inch was equivalent to 1 I.H.P. As this 52 I.H.P. at Torquay was from two boilers, and in the cases he had given previously the actual I.H.P. from one boiler was 124, at 70 lbs. per square inch, and from two boilers 350 I.H.P. at 113 lbs. per square inch, further detailed comparison was therefore unnecessary, there being so marked a difference. Seventhly, he himself ventured to suggest that the author, in stating that the slower the combustion and the lower the temperatures the better were the results obtained, must have overlooked some of the better designs of destructors, for during a considerable experience in destructor work he himself had found just the opposite to be the case. The higher the temperature in the destructor and the higher the rate of combustion, the better were the all-round results. It would therefore be interesting to know, with what makes of high-temperature destructors and over what lengths of time the author had gained his experience. The previous cases just quoted from north and west of England were high-temperature destructors, and the results spoke for themselves. Eighthly, some explanation was due of the statement on page 425, Test 1, that the boiler-pressure reached 105 lbs., seeing that the safety-valves were set (page 422), so that the boilers blew off at a working pressure of 80 lbs. per square inch. Ninthly, in connection with the proposed manufacture of disinfectant powder from the flue dust, it was interesting to note that the dust from destructor flues, etc., had been used as a

(Mr. R. B. Hogdson.)
basis of making carbolic powder successfully and profitably at Rochdale for the past fifteen years, originally in a low but now in a high-temperature destructor. Another works could comfortably dispose of over 100 tons of clinker-made mortar per day, if they had so much material.

Mr. GARRETT, writing in reply to the discussion and correspondence, ventured to remark that no electrical engineer or electric-light company would care to rely solely upon a destructor, however perfectly constructed or designed it might be, if fed with towns' refuse only as fuel for steam raising in central electricity works for public and private lighting. Cremation was undoubtedly the best method of disposing of towns' refuse, the question of cheapness depending somewhat upon local circumstances in each case. In the selection of a site for a destructor, a spot as near the centre of collection as possible was recommended. The saving on cartage and the revenue from residuals would generally be found to go a long way towards the cost of working and maintenance. Mr. Terry's remarks (page 431) were extremely interesting and valuable, especially with regard to "dust-catching arrangements"; and manufacturers would no doubt give attention to this point. In the Torquay destructor a dust-catching chamber with a deflecting wall was provided, and answered very satisfactorily. He regretted he could not accept Mr. Hodgson's comparison (page 434) as fair, for that gentleman did not give either the name of the town or the type of destructor, or the component parts of the refuse he wished to bring into comparison with Torquay and its refuse. The author desired again to assert that in his opinion it was principally a question of calorific value in the refuse to be treated; and he believed he had obtained at Torquay a record in evaporative powers with the refuse at his command; also that there was practically no difference in the amount of carbonic acid in the chimney gases, when destructors were working at about the same temperature. The temperature in the Torquay destructor had been found to be quite as high as any in use. Evidence of this was recorded by the burning of the iron tube and melting of the copper rod in a pyrometer, the remains of which were in possession of the author.

With regard to the pressure gauge registering 105 lbs. of steam, the safety-valve was of the lever and weight type, and was tested to 300 lbs. pressure; it would be perfectly safe if worked at 150 lbs. pressure.

EXCURSIONS.*

On Tuesday Afternoon, 25th July, after luncheon in the Pavilion on the Promenade Pier, a visit was made by special steamer to H.M. Dockyard, Devonport, under the guidance of the Dockyard Officers, by permission of the Lords of the Admiralty. The Council and Members afterwards attended the opening of the Devonport Municipal Technical School, when a Memorial stained-glass Window was unveiled by the President. Subsequently the Members and Ladies accompanying them attended a large Public Meeting in Devonport, at which the President was presented by the Mayor with the Freedom of the Borough of Devonport.

The following Works were open to the visit of the Members in the afternoon, also on Wednesday afternoon, and on Thursday and Friday :—

Municipal Electrical Works, Prince Rock.
Municipal Free Public Library, Old Guildhall.
Municipal Science, Art, and Technical Schools, Tavistock Road.
Municipal Science, Art, and Technical Schools, Devonport.
The Athenaeum (Plymouth Institution and Devon and Cornwall Natural History Society), George Street.
Marine Biological Laboratory, Citadel Hill.
Bickle and Co., Engineering Works, Great Western Docks.
Bywater and Co., Millbay Engineering Works, Great Western Docks.
Devon and Cornwall Ice and Cold Storage Works, 7 St. Andrew's Street.
Ellacott and Sons, Engineering Works, Great Western Docks.
E. James and Sons, Starch Mills, Sutton Road.
Willoughby Brothers, Engineering Works, Rendle Street.

In the evening the Institution Dinner was held in St. Andrew's Hall. The President occupied the chair; and the following Guests accepted the invitations sent to them, though those marked

* The notices here given of the various Works, &c. visited in connection with the Meeting were kindly supplied for the information of the Members by the respective authorities or proprietors.

with an asterisk* were unavoidably prevented at the last from being present.

The Worshipful the Mayor of Plymouth, Alderman John Pethick; the Worshipful the Mayor of Devonport, William Hornbrook, Esq.; the Chairman of the East Stonehouse Urban District Council, J. E. Bone, Esq., J.P.; the Worshipful the Mayors of Bodmin, Launceston, Liskeard,* Penryn, Penzance,* St. Ives, Saltash, Tiverton, and Truro; Mr. Hudson E. Kearley, M.P., and Mr. E. J. C. Morton, M.P.; Professor W. Cawthorne Unwin, F.R.S., Honorary Member; and Mr. James Paton, Honorary Local Secretary.

Naval and Military Authorities.—Rear-Admiral Thomas S. Jackson, Admiral Superintendent, Devonport; Colonel George Poignand and Colonel Harry Cooper,* A.D.C., Assistant Adjutant-Generals, Western Command; Mr. George Crocker, Civil Assistant to the Admiral Superintendent; Mr. H. R. Champness, Chief Constructor H.M. Dockyard, Devonport; Mr. Robert Mayston, Chief Engineer H.M. Dockyard, Devonport; Staff-Captain J. B. Johnson, Queen's Harbour Master; Mr. C. Millard, Civil Engineer H.M. Dockyard, Devonport; Professor A. M. Worthington, F.R.S., Head Master, Royal Naval Engineering College, Devonport; Mr. J. H. Adams, Chief Engineer, Royal Naval Engineering College.

Sir John Jackson, F.R.S.E., Contractor for the Keyham Extension Works; Mr. Whately Eliot, Admiralty Superintending Civil Engineer, Keyham Extension Works; Mr. George H. Scott, Keyham Extension Works.

Municipal Authorities, Plymouth.—Mr. Henry E. Duke,* Q.C., Recorder; Mr. John H. Ellis, Town Clerk; Mr. G. Gregory Davey,* Borough Treasurer; Mr. W. H. K. Wright, Borough Librarian; Mr. Edward Sandeman, Borough Water Engineer; Mr. John H. Rider, Borough Electrical Engineer. Mr. T. Greek Wills, Chairman, Incorporated Chamber of Commerce; Mr. R. Trevithick,* Ex-Chairman, Incorporated Chamber of Commerce; Mr. Alfred Latimer, Secretary, Incorporated Chamber of Commerce.

Municipal Authorities, Devonport.—Mr. Alderman G. T. Rolston;

Mr. Alderman Stanbury; Mr. A. B. Pilling, Town Clerk; Mr. James Neal, Secretary, Municipal Technical School.—Mr. Henry A. Garrett, Borough Engineer and Surveyor, Torquay; Mr. William Ingham, Borough Water Engineer, Torquay.

Mr. H. Y. Adye,* Divisional Passenger Superintendent, Great Western Railway, Plymouth; Mr. E. J. Allen,* Secretary, Marine Biological Association, Plymouth; Mr. Moses Bawden,* Devon Great Consols Mines, Tavistock; Mr. J. H. Collins*; Mr. B. M. Evans, President, Plymouth Institution; Mr. Henry T. Ferguson*; and Mr. T. H. Gibbons, Divisional Engineer, Great Western Railway, Plymouth.

The President was supported by the following officers of the Institution:—*Past-Presidents*, Sir Frederick Bramwell,* Bart., D.C.L., LL.D., F.R.S., and Mr. Percy G. B. Westmacott; *Vice-Presidents*, Mr. William H. Maw and Mr. A. Tannett Walker; *Members of Council*, Mr. Henry Chapman, Mr. Henry Davey, Mr. Bryan Donkin, Mr. Edward B. Ellington, Mr. H. Graham Harris,* Mr. Henry Lea, and Mr. John I. Thornycroft, F.R.S.

After the usual loyal toasts, that of "The Navy, Army, and Auxiliary Forces" was proposed by Sir John Jackson, and was acknowledged by Rear-Admiral Thomas S. Jackson, Admiral Superintendent, and by Colonel George Poignand, Assistant Adjutant-General. Mr. Hudson E. Kearley, M.P., proposed the toast of "The Mayors and Municipalities of Devon and Cornwall," which was acknowledged by the Worshipful the Mayor of Plymouth, Alderman John Pethick, and by the Worshipful the Mayor of Launceston, Councillor William Prockter. The concluding toast of "The Institution of Mechanical Engineers" was proposed by the Worshipful the Mayor of Devonport, William Hornbrook, Esq., and acknowledged by the President.

On Wednesday Afternoon, 26th July, the Members and Ladies accompanying them proceeded in special brakes from the Guildhall to the Keyham Extension Works. After luncheon in a marquee, by invitation of Sir John Jackson, contractor for the Works, the

Members were conducted round in parties, and the various mechanical appliances mentioned in Mr. Whately Eliot's Paper (page 365) were seen at work. Afterwards the Keyham Dockyard and Steam Factory and the Royal Naval Engineering College were visited, and the return journey was made viâ the Great Western Railway viaducts and bridges (page 355), namely Keyham Viaduct, Weston Mill Viaduct, and the Royal Albert Bridge at Saltash, which the Members were enabled to inspect under the guidance of Mr. T. H. Gibbons, Divisional Engineer. Another party went for a trip on the Hamoaze and round the Breakwater in a steam-launch lent by Sir John Jackson.

On Thursday, 27th July, four alternative Excursions were made.

One was by special train to Yelverton, and thence by brakes over Dartmoor to Princetown. After luncheon in a marquee, the Members drove to Burrator and visited the new reservoir and masonry dam of the Plymouth Water Works, under the guidance of Mr. Edward Sandeman, Borough Water Engineer. The return journey to Yelverton and Plymouth was made viâ Dousland, where tea was served at the Manor Hotel.

Another excursion in the afternoon was made by special train to Tavistock, and thence by special brakes to the Devon Great Consols Mines, which were visited under the guidance of Mr. Moses Bawden, General Manager. After tea in the Count House, the return journey was made by brakes to Calstock, and thence by special steamer down the River Tamar to Plymouth.

The third excursion was made by special train to Bere Alston, followed by a short walk to the River Tamar, where the ferry was taken to Cotehele Quay. The Grounds, old Dining Hall, and Chapel belonging to Cotehele House, were visited by permission of the Right Hon. the Earl of Mount-Edgcumbe. After tea at Calstock, the return journey to Plymouth was made by special steamer down the River Tamar.

The fourth excursion was made by special steamer up the River Tamar to Calstock, passing the government establishments at

Devonport and Keyham, the training ships, battleships, and under the Royal Albert Bridge at Saltash. Tea was served at Calstock, and the return journey was made down the River Tamar to Plymouth.

On Friday, 28th July, various excursions and short trips were made. In the morning the Gunnery School on H.M.S. "Cambridge" and the Torpedo School on H.M.S. "Defiance" were visited in the Hamoaze by special steamer.

The Park and Italian Gardens at Mount Edgcumbe were open to the visit of Members and Ladies in the afternoon.

A party of Members visited the Eddystone Lighthouse, by special steamer, under the guidance of Mr. W. T. Douglass, who had been engineer in charge during its construction.

The Worshipful the Mayor of Plymouth, Alderman John Pethick, also invited the Members and Ladies to a Garden Party in the afternoon at Down House, Yelverton.

During the week of the Meeting the Right Hon. the Earl of St. Germans opened his Grounds and Gardens at Port Eliot to the visit of the Members and Ladies.

H.M. DOCKYARD, DEVONPORT.

There is nothing of importance in common between Devonport Dockyard to-day and the establishment which existed far into the seventeenth century. With the gradual increase of the Navy there has necessarily been a corresponding expansion of the government establishments, and at none of the home ports has this development been more marked than at Devonport, Plate 129.

The Dockyard was founded by William III. in 1688, on a spot known as Point Froward, northward of which was a little inlet, which became the first basin, and its upper end the first dock. The wisdom

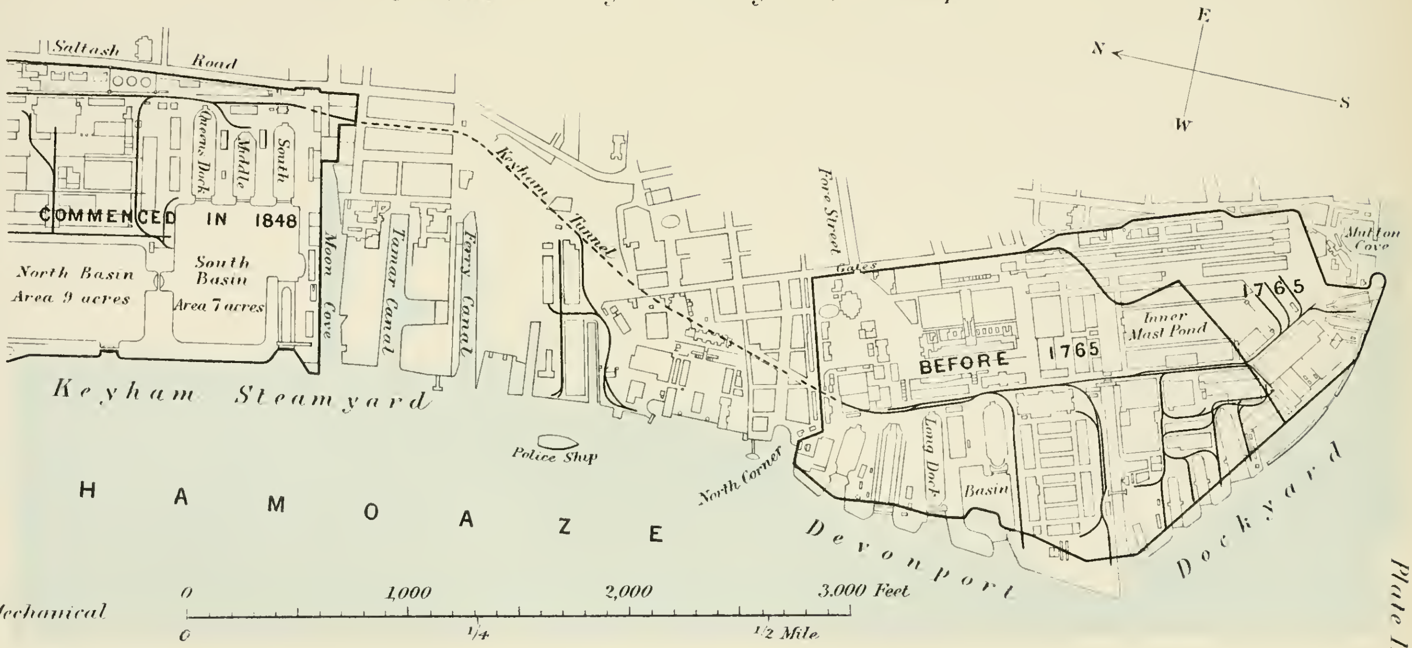
of William III. in recognising the geographical importance of Plymouth for the purposes of the Navy has been justified beyond measure, and the latest proof of it is to be found in the Keyham extension scheme, Plate 130, which, when completed, will form an almost continuous line of government works for a distance of three miles, commencing with the building sheds and terminating with the Ordnance Depôt at Bull Point. The first section of "Plymouth Dockyard" (the name which it retained until 1824) was finished in 1693, and extended from the present jetty at North Corner to the existing camber, being enclosed by a wall on the north and east sides. The area then enclosed for the purpose of the yard was not more than thirty-five acres, which was soon found to be too small. Extensions were therefore made in 1727, and also the formation of a second dock at the north end of the yard, and a further extension in 1798. Now the area of the yard and of Keyham Factory, excluding the extension now in progress, is about 143 acres; and it is all closely covered with shops, rope-walks, smithies, stores, docks, and building slips.

The main entrance is in Fore Street, Devonport. The first building to attract attention is the chapel, and adjacent thereto is the head-quarters of the Dockyard Police, a building formerly used as the military guard-house. Near this is the surgery to which artisans injured while on duty are taken, preparatory to being removed to their homes or to the Royal Naval Hospital. Secluded by an avenue of trees are the residences of the officials. Two flights of stone steps lead to the docks and workshops, which can also be reached by the main road. Facing the central flight of steps is the (now enlarged) dock and basin constructed in the reign of William III. The basin is oblong in shape and bounded riverward by jetty-heads, with platforms projecting over the water supported by wooden piles. Within the basin is the dock which is generally used for repairing vessels of moderate draught and dimensions. In a northerly direction from this are three more docks, the northernmost one of which, near the four flights of steps, was constructed in 1789, and opened in the presence of George III. The centre one has recently been enlarged to accommodate our largest battleships, and the adjoining

ROYAL DOCKYARD, DEVONPORT.

Fig: 1.

Growth of Royal Dockyard, Devonport.



Continued on Plate 130.

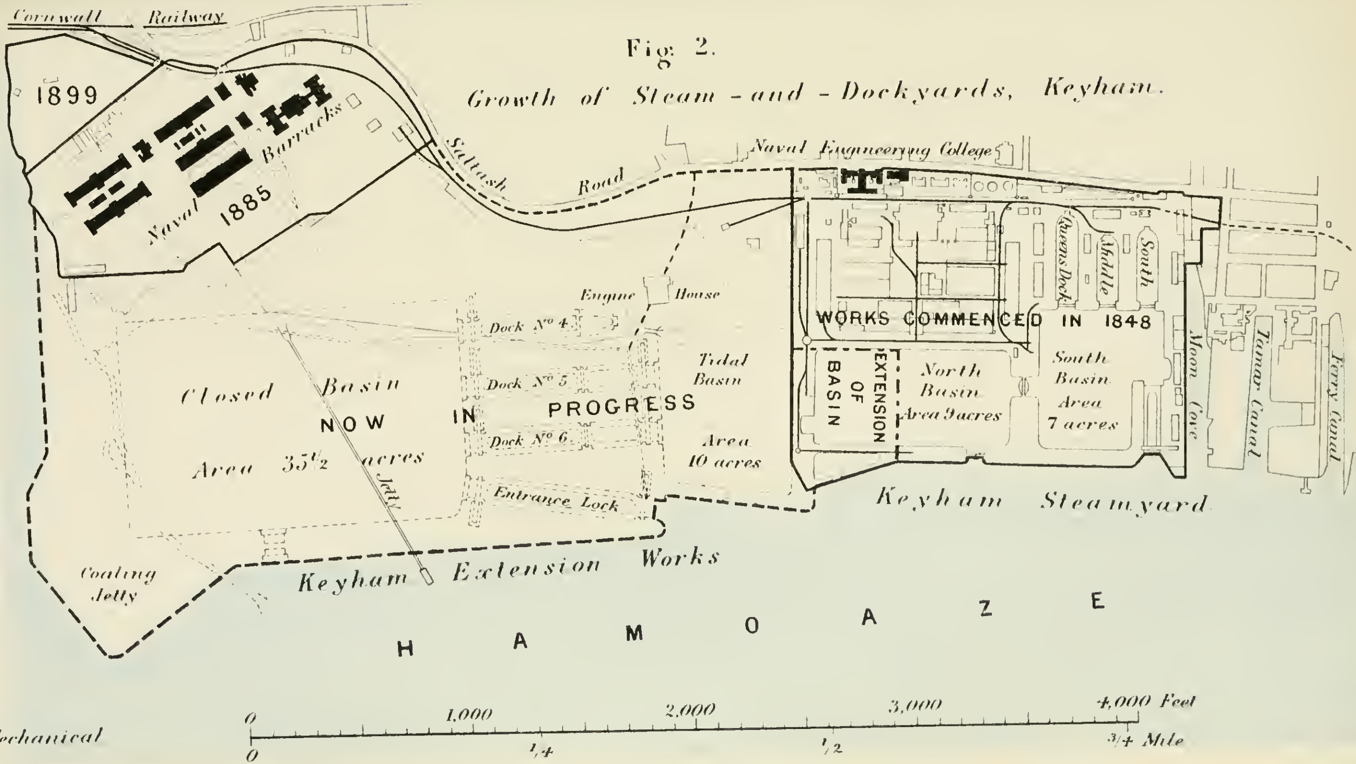
Mechanical Engineers 1899.

Plate 129.

STEAM-AND-DOCKYARDS, KEYHAM.

Fig. 2.

Growth of Steam-and-Dockyards, Keyham.



Continued from Plate 129.

Plate 130.

dock southward has been similarly extended, so that it will now take all but the largest cruisers.

Two ranges of buildings, used as workshops and offices, stand in front of the docks; and running parallel with the southernmost dock are two long edifices, the eastern of which is known as the rigging-house, and contains some valuable specimens of figure-heads, while the other is used as a sail loft. Across the camber are the various workshops, smithy, ropery, &c. In the ropery practically half the hempen ropes used in the Navy are made; the only other Government establishment of the kind is at Chatham. About 100 women are employed here at this work. Emerging from the workshops the building slips are next seen. Four of them are still covered with roofs, the larger one measuring over 6,000 square yards. One of the "sheds" was recently converted into an open slip, for the construction of Devonport's first battleship—the "Ocean"—in 1897. The King's Hill is an eminence on which a pavilion is erected, and was preserved from being levelled with the ground around to commemorate the visit of George III. in 1780. It commands a magnificent prospect of the Dockyard and Hamoaze. The number of workmen engaged here is about 7,400.

A tunnel over half-a-mile in length connects the dockyard of Devonport with the modern steam-yard and factory at Keyham and the military Gun Wharf. The latter was built between 1718 and 1725, to the designs of Sir John Vanbrugh, and is the depôt of the ordnance stores.

H.M. FACTORY AND DOCKYARD, KEYHAM.

This Factory and Dockyard, Plate 130, which were commenced in 1844 and opened in 1853, occupy over seventy-two acres of land. They comprise three spacious docks and two basins, most of which are constantly in use, either with vessels passing through the "completing stage," or others refitting for further service. Immediately inside the entrance, which has an imposing appearance, are the offices of the Dockyard Reserve. The most prominent feature of the factory

consists of two immense chimneys, each 180 feet high, and into which the smoke from numerous furnaces is carried by means of underground or overhead flues. The factory is in the form of a quadrangle, the sides of which are made up by machinery shops, stores, an instructional shop for engineer students, smithy, erecting shop and turnery, iron and brass foundries, pattern and millwrights' shops, plate-flanging works, &c., Plate 120. The largest of the docks is "The Queen's Dock," which is 418 feet in length, and derived its name from the fact that "The Queen" was the first vessel to enter it.

KEYHAM DOCKYARD EXTENSION WORKS.

In 1895 the Admiralty finally decided to carry out a scheme of extension at Keyham, and before the close of the following year Sir John Jackson, the contractor for the Manchester Ship Canal, had commenced to carry out this most important extension, Plates 109 and 130. Hitherto the dockyard and factory have covered nearly 144 acres, and the extension includes the utilization of another 100 acres of land beyond the termination of Keyham Yard and the Royal Naval Engineering College. The contract, which amounts to £3,175,000, provides for a large tidal basin, with an area of 35½ acres—1,550 feet long, 1,000 feet wide, and 55 feet deep—communicating with the Hamoaze by a caisson. The scheme also provides for three graving docks and a capacious entrance-lock. When this extension is completed—in about six or seven years' time—the port will be provided with the following dock and basin accommodation :—

	Docks.	Basins.
Devonport	4	1
Keyham	3	2
Keyham Extension	3	2
Total	10	5

The Admiral Superintendent of Devonport is Rear-Admiral Thomas S. Jackson, who succeeded Rear-Admiral Henry J. Carr early in the present month of July.

A description of the mechanical appliances used in the construction of these Extension Works is given in Mr. Whately Eliot's Paper (page 365).

ROYAL NAVAL ENGINEERING COLLEGE, DEVONPORT.

This College, situated just outside the north end of Keyham Dockyard, Plate 130, is the only educational establishment of the kind in the United Kingdom. It is a large and handsome edifice of Portland stone. The mess-hall is 69 feet long and 30 feet high by 29 feet in width, with a splendid wagon roof; and the building contains airy dormitories, class-rooms, and every other needful convenience. In 1896 a new wing was added at the south end of the College at a cost of £30,000.

Students enter by competitive examination between the ages of 14½ and 16½ years, and remain five years under training, about two-thirds of their time being devoted to practical engineering work and the remainder to mathematics and physics. The students number about 200, all residing at the College, under the charge of Commander Hugh Talbot, R.N. (*See also Mr. Robert Mayston's Paper, page* 377.)

CORPORATION ELECTRICITY WORKS, PLYMOUTH.

These works stand upon land owned by the corporation, and are situated a few hundred yards below the Laira Bridge. The building faces the Cattewater, but is separated from it by the Cattewater branch of the London and South Western Railway. The total area of ground covered is 150 feet length by 130 feet width, and the chief dimensions of the building are:—engine-room 100 feet by 40 feet, boiler-house 100 feet by 56 feet, administration block 100 feet by 20 feet, coal and other stores 40 feet by 56 feet,

yard 40 feet by 60 feet. The building is of limestone obtained on the site, with facings of red brick. The chimney is 180 feet high by 8 feet internal diameter.

The engine-room contains two 150-B.H.P. Belliss compound vertical condensing-engines, 375 revolutions, coupled through coil clutches to 100-kilowatt Ferranti alternators, and 100-kilowatt Westinghouse dynamos; two 300-B.H.P. Ferranti compound vertical condensing-engines, 250 revolutions, coupled direct to 200-kilowatt Ferranti alternators; three Ferranti rectifiers, each for fifty 10-ampère arc-lamps; three 6-inch Gwynne centrifugal-pumps, motor-driven, for lifting sea-water into tank for condensers; one overhead travelling-crane of 40 feet span, for 15 tons, worked by hand; three switchboards, one for lighting, of Ferranti standard type, another for tramways (Westinghouse Co.), and one for arc-lamps of the Ferranti type. Each engine has a Körting ejector-condenser, supplied with sea-water from a tank. The exhaust-steam can be taken either to the condenser or direct to the atmosphere through a common pipe. Space is provided in the engine-room for an additional set of 700 H.P.

The boiler-house contains three Lancashire boilers 30 feet by 7 feet 6 inches, made by Messrs. J. Musgrave and Sons, for 160 lbs. pressure; three Vicars' mechanical stokers; one Green's economiser, containing 256 tubes; two three-throw electrically-driven feed-pumps, made by Messrs. Hayward Tyler, for 4,000 gallons per hour; and one live-steam injector. Boilers can be fed either from the town mains direct or from a storage tank on the roof. Coal is supplied through shoots from stores overhead. The steam pipes are made of steel, with copper bends, and no pipe has a larger diameter than 7 inches. There is no steam-ring, nor are there duplicate mains; a pipe leads direct from each boiler to each engine with one cross connection. The full-way valves were made by Messrs. Hopkinson and Fletcher, and the boiler mountings by Messrs. Hopkinson. The stokers and economiser-scrapers are driven from a common shaft by an electric motor. Space is provided for three more boilers and an economiser of equal size. The two water-tanks, one for fresh and the other for sea-water have a capacity of

28,000 gallons each, and form the roof over the coal stores; they are constructed of cast-iron plates with machined joints. The accumulators contain 260 "Tudor" cells of the L.B.11 size, for 600 ampère-hours, the maximum discharge rate beiug 200 ampères. The battery is in parallel with traction bus-bars, and is charged from them with a motor-driven booster in series.

The administration block includes offices for the staff, test rooms, and stores, &c. A siding from the London and South Western Railway runs into the yard and engine-room, so that the crane can be brought directly over the trucks. This is the first station in the country designed for combined lighting and traction load, though, owing to delay in completion, not the first in actual operation. It is however the only instance of station driving lighting and traction from the same engine at one time. The capital outlay amounts to £56,000, and the charges for current are $4\frac{1}{2}d.$ per unit for private consumer, $3\frac{1}{2}d.$ for tramways, and £16 per arc-lamp per annum which includes trimming.

Tramways.—The gauge is 3 feet 6 inches, and rails weigh 92 lbs. per yard. The overhead system is installed on Prince Rock route, and there is $1\frac{1}{2}$ mile of double-track roadway. Side bracket arms and span wires are fixed, and the cars are double-deck with swivelling trolley on centre of roof. Each car carries two 25-H.P. Westinghouse motors. The brake is worked by hand or by a graded electric-brake, using motors. The trucks are of the "Peckham" type, with "Milnes" car-bodies. Three "Chicago" bonds are fixed to each joint, and cross bonds to every three-rail lengths. The rails form the return circuit without auxiliary conductors. Current is supplied to the overhead line by the electricity department. The capital cost of equipment amounts to about £7,500. The borough electrical engineer is Mr. John H. Rider.

CORPORATION FREE PUBLIC LIBRARY, PLYMOUTH.

This Library was opened in 1876, the Libraries' Act having been adopted in 1871. It occupies the old Guildhall (erected in 1800),

to which additions have been made from time to time to meet the rapid growth of the Institution. The building stands in the very heart of Old Plymouth, surrounded by many relics of Elizabethan days. In addition to the Central Library in Whimple Street, there are Branch Reading Rooms with small libraries attached in outlying districts, and also a system of School Libraries, by which all the Board Schools and several voluntary schools are supplied with books from the Central Library. In this way all the elementary schools of the town are served. This system, which was initiated by the Plymouth Free Library, has recently been favourably reported upon by the Education Department.

The Central Library contains over 45,000 volumes, in addition to a large collection of patent specifications, which are accommodated in the basement. There is a reference library upon the upper floor, containing about 20,000 volumes, and a lending library with all modern appliances containing nearly 25,000 volumes. One special feature of the reference library is a room devoted to Devon and Cornwall literature; this department alone comprises over 10,000 separate works. The circulation of books averages over one thousand per day. In the basement is the general news room, well supplied with current periodicals; on the first floor (in the old Guildhall) is the magazine room and the ladies' reading room. The Library is managed by a committee, appointed by the Borough Council, half from their own body and the other half of outside members, the Mayor being chairman ex officio. The Librarian, Mr. W. H. K. Wright, Fellow of the Library Association and of the Royal Historical Society, was appointed early in 1876, and has therefore carried out the whole work of organization from the outset up to the present time. He has made, in addition to the local collection of books and pamphlets, a large collection of prints, portraits, and sketches of Plymouth and district, and is the author of various works of local interest.

MUNICIPAL SCIENCE, ART, AND TECHNICAL SCHOOLS, PLYMOUTH.

These Schools are situated in Tavistock Road, the northern main approach to the town. They were erected by public subscription as a memorial of the Queen's Jubilee on land given by the corporation. On their completion they were handed over by the building committee to the town, and were opened for work in October 1892.

In the basement are the carpenters' shop, plumbers' shop, mechanical and electrical engineering shop with gas-engine, dynamo and screw-cutting lathe, also rooms for cookery lessons, wood-carving and casting. The first floor comprises drawing-office for machine and building construction, physical laboratory, lecture theatre with preparation room, mathematical and other class rooms, elementary art room, committee room and offices. On the second floor are chemical laboratory with balance room, lecture room for physiology, hygiene and chemistry, dressmaking room, large antique room, life room and modelling room.

The work of the Schools consists of:—

(1) Advanced Day classes, giving to persons above the ordinary school age the means of continuing their education in science, art and languages. The science work is of such a character as to fit students for the degree examination of the University of London, and to give the scientific training needed by those who intend to enter professional life, or to become science teachers, or who wish to compete for national and other scholarships. The Art training is for those who wish to follow art professionally, as well as for all who desire an art education as a means of self-culture.

(2) Preparatory Day classes, for pupils whose elementary education is completed, and who desire a course of training as will best fit them to become chemists, engineers, &c.

(3) The advanced section of a School of Science. The elementary portion of this work is done at the Higher Grade Board School, and the scheme is worked under a joint committee.

(4) Evening Classes in Science and Art at low fees are held to meet the wants of artizans, clerks, teachers, and others who are engaged during the day. Classes are carried on in connection with the City and Guilds of London Central Institution in mechanical and electrical engineering, plumbing, carpentry, typography, dressmaking and manual training (woodwork). Language and commercial classes are also held. The schools are recognised by the conjoint board of the Colleges of Physicians and Surgeons as giving instruction in chemistry, physics, biology and pharmacy, which qualifies for the first examination of the board. Medical students can thus have one *annus medicus* at these schools, which saves them subsequently one year's residence from home.

A complete set of apparatus has been provided for work with the *x* rays, which has proved of great value to the local hospitals and members of the medical profession.

Numerous and important successes have been gained by students of the schools both in science and art, and in technological and commercial examinations, and the work of the schools has developed to such an extent that the Town Council have sanctioned the extension of the buildings at a cost of £9,000.

The Chairman of the Committee is Alderman J. Shelly, and the Secretary Mr. T. W. Byfield. Mr. J. Burns Brown, B.Sc., is Head Master of the School of Science and Technology, and Mr. Frederick Shelley, A.R.C.A., Head Master of the Art School. The number of students attending the schools is 800.

MUNICIPAL SCIENCE, ART, AND TECHNICAL SCHOOLS, DEVONPORT.

In 1892 the Devonport Borough Council nominated a Technical Instruction Committee to collect information respecting existing Science and Art classes in the Borough, and, acting on the advice of the Science and Art Department, the Committee sought for suitable premises in which to co-ordinate and extend these classes. A temporary building was rented in George Street until more

convenient and commodious premises could be obtained. After much delay the Committee succeeded in negotiating with the War Office for the purchase of a plot of ground about $\frac{3}{4}$ acre in extent, in close proximity to the Devonport station of the London and South Western Railway. The building was commenced in 1897, and the memorial stone, to commemorate the Diamond Jubilee of Her Majesty, was laid by the Mayor, W. J. Waycott, Esq., J.P., on 22nd June 1897.

The plan of the building is rectangular, being about 150 feet long and 70 feet wide, and is built of limestone with Ham Hill stone dressing. It has basement, ground and first floors. There are three entrances, the main one being in the centre of the south elevation. In the centre of the north elevation and immediately opposite the main entrance is a handsome memorial window, emblematical of the advance which has been made during the reign of Her Majesty in science and art, engineering and naval architecture. This window has been presented by the present Mayor, William Hornbrook, Esq. In the basement are rooms for mechanical engineering, manual training in wood work, also boiler room, engine room, clay-modelling room, plumbers' workshop, and apartments for the caretaker. On the ground floor are five class-rooms, large lecture hall (used also for mechanical drawing), committee room, and secretary's office, while on the first floor are chemical and physical laboratories and lecture room at the west end, and three art rooms and a commercial room at the east end. Cloak rooms and lavatories are provided at both ends on each floor. A staircase is provided at each end, and a central one from the ground floor to the basement, the lower part being of stone, and the upper of wood, with handsome iron balusters and oak hand-rail. A spacious corridor divides each floor laterally, the dado being 4 feet high and of pitch-pine varnished. The class-rooms on each side of the corridors are light and lofty, and will accommodate from forty to fifty students. Classes are conducted in connection with the Science and Art Department, the City and Guilds of London Institution, the Society of Arts, and the Worshipful Company of Plumbers.

Being a dockyard borough, as might be expected a large proportion of the students in science are or have been connected with the dockyard, about 80 per cent. being drawn from this source, and the largest and most popular classes are those in mechanical sciences. In spite of the unfavourable conditions under which their work has been carried on in the past, the Committee have much reason to be gratified at the success of their efforts to promote technical education in the borough, for since the schools have been opened there have been awarded five National Scholarships, nine Royal Exhibitions, thirteen Whitworth Exhibitions, seven Queen's Prizes and three Shipwright Company's prizes. Much of the credit of what has been achieved at these schools is due to the keen interest and untiring perseverance of Mr. Alderman Banister, J.P., who has been Chairman of the Technical Instruction Committee for the last five years. The Secretary is Mr. James Neal.

PLYMOUTH INSTITUTION AND DEVON AND CORNWALL NATURAL HISTORY SOCIETY, THE ATHENÆUM, PLYMOUTH.

The Plymouth Institution was founded in 1812 "for the delivery of lectures, and for discussions on the different subjects of Science, Literature, and the Fine Arts, for the formation of a Library, Collection of Apparatus, and Museum," and in 1851 was amalgamated with the Devon and Cornwall Natural History Society. The Institution possesses a valuable Library and Museum, with Lecture Hall and other rooms.

The library consists for the most part of scientific works and sets of the leading scientific periodicals, besides many valuable portraits, paintings, drawings, and engravings. The Museum is rich in local and other collections, illustrating the various branches of science; it contains also some valuable collections relating to prehistoric man, which have been discovered in the immediate neighbourhood. The natural history collections are also good, that of British birds being very valuable and almost complete, particularly from a local point of view.

MARINE BIOLOGICAL ASSOCIATION LABORATORY, PLYMOUTH.

The Marine Biological Association of the United Kingdom owes its existence to a combination of scientific naturalists and of persons interested in the sea-fisheries of the United Kingdom. On the one hand, our knowledge of the habits and conditions of life of sea-fishes is small, and insufficient to enable either the practical fisherman or the government to take measures calculated to ensure to the country the greatest possible return from the "harvest of the sea." On the other hand, naturalists are anxious to obtain increased information about marine animals and plants.

The Laboratory of the Association, which was built at Plymouth at a cost of about £12,000, was opened in 1888, and since that time practical and scientific investigations have been constantly pursued. On the ground floor of the building is the aquarium, fitted with a number of large tanks, in which a variety of fishes and invertebrate animals are kept in a living state. A constant circulation of sea-water is maintained through these tanks from two large storage reservoirs situated at the back of the building, each having a capacity of 50,000 gallons. The water is pumped from the reservoirs by a gas-engine driving a rotary pump of vulcanite, all the pipes and fittings being also of the same material. The reservoirs themselves are supplied with water from the sea by means of an ejector, worked also by a gas-engine.

On the ground floor, in addition to the aquarium, there is a collection of preserved specimens of fishes and other marine animals. The laboratory proper, or work-room, is over the aquarium, and is fitted with twelve compartments, which are occupied by naturalists carrying on investigations. The remainder of the building contains the library, museum, and various work-rooms. A small steamboat is maintained by the Association, and is kept in daily use. It is fitted with trawls, dredges and nets of different patterns for the capture of marine animals and plants.

The scientific staff consists of a resident director, who is also secretary, a naturalist engaged in fishery investigations and an assistant naturalist. The other workers in the Laboratory come from Oxford and Cambridge, and from various teaching institutions throughout the country. A "Journal" containing an account of the researches carried on by the Association is published twice yearly. A large number of memoirs containing valuable contributions to science, the result of work done in the Laboratory, have also appeared in the Transactions of learned societies and in scientific periodicals during the last ten years.

The income of the Association is derived partly from a grant from H.M. Treasury (£1,000), from a grant from the Fishmongers' Company (£400), and from the annual contributions of members of the Association (£140).

MESSRS. BICKLE AND CO., ENGINEERING WORKS, PLYMOUTH.

These works are situated at the Great Western Docks, having been established in 1887 for carrying out general engineering work. The principal productions comprise pumping and winding machinery, Chilian mills, Cornish crushers, air-compressors, and general mining requisites. The "Bickle" rock drill, a speciality of this firm, has proved a very simple and most effective machine. They also manufacture marine and Lancashire boilers, the latter up to 7 feet 6 inches diameter by 30 feet long. A considerable business is done in marine-engine and ship repairs, the premises being at the waterside, and adjoining large graving docks. The works are at present engaged in the manufacture of a triple-expansion mill-engine of 250 I.H.P., using steam at 200 lbs. pressure; also large Cornish crushers, air-compressors and rock-drilling machinery. The number of men employed is about 170.

MESSRS. BYWATER AND CO., MILLBAY ENGINEERING WORKS, PLYMOUTH.

These works, founded in 1891, are situated in the Great Western Railway Docks, having a railway and water frontage. They are engaged on Admiralty and War Department engine and boiler work, in addition to ordinary constructional, foundry, smithy, and general engineering work. The number of men employed is about 100.

DEVON AND CORNWALL ICE AND COLD STORAGE WORKS, PLYMOUTH.

These works, situated in St. Andrew Street, consist of an ice factory capable of turning out 20 tons of ice per day, partly on the can system and partly on the cell system. They have a cold-storage capacity of about 50,000 cubic feet. The refrigerators, made by Messrs. J. and E. Hall, of Dartford, are of the mechanical compression type, using carbonic-acid gas as the refrigerant. The whole factory is now in full operation under the charge of Mr. A. C. L. Back, A.M.I.Mech.E.

MESSRS. ELLACOTT AND SONS, PLYMOUTH FOUNDRY AND ENGINEERING WORKS, GREAT WESTERN DOCKS, PLYMOUTH.

These old-established works are situated on the eastern side of the Great Western Docks, having both a railway-siding and water frontage. The work done is principally for local requirements of the various departments of the government, county and district councils, harbour, electrical, gas, water, and other works. The machines are driven by one of the latest "National" gas-engines, with shafting on each side of workshop. An overhead traveller runs

the whole length of the works and through the front over the railway trucks to facilitate the unloading and despatch of goods. The works were formerly situated in the centre of the town.

MESSRS. EDWARD JAMES AND SONS, STARCH, BLUE, AND BLACKLEAD MANUFACTURERS, PLYMOUTH.

These works are situated at the eastern end of the town, close to the Sutton Harbour Branch of the Great Western Railway, and most conveniently placed for waterside transit. Established in 1840 by the late senior partner, Mr. Edward James, then a member of the firm of Messrs. Bryant, James, and May, merchants, Plymouth, it has steadily grown in size and importance until its productions have obtained a world-wide celebrity. A portion of the ground on which the premises now stand was originally in the occupation of a Roman Catholic Sisterhood, known as the "Poor Clares," who subsequently returned to their native place in France, early in the nineteenth century. About the year 1840 the premises were purchased for the purpose of a starch manufactory, and have been so continued ever since, although the present appearance of the site, with the high buildings and tall chimneys, is very different from that when deserted by the nuns. The firm is well known throughout the world, and the addition many years since of the manufacture of ultramarine blue for laundry purposes, and of blacklead, has immensely added to its importance. They are the inventors and sole manufacturers of the "Dome" brand of blacklead.

Starch is not strictly speaking a manufactured article. It exists more or less in all grain and in many roots. The starch manufacturer has to extract the starch and produce it in a form suitable for the laundry. Rice is used as the most productive grain for starch making. After it has been cleaned and steeped in a prepared liquor, the soft grain passes through mill-stones, of which the mill-room contains many sets. The result is a substance something like raw cream. This is sent by means of pumps to the top floor of the

building, where in deep wooden vessels it is treated chemically, and is then passed into other deep vessels called vats, in which it is agitated by machinery. The starch portion of this liquid mass is next drawn off and conveyed by shutes to the "flats" for settling, the fibre of the grain remaining in the vats to be dealt with for other purposes. From the flats the starch is collected, and after further treatment is run into long narrow boxes to solidify. It is then turned out and cut into cubes about six inches square. In this form it passes into "crusting stoves," and is subjected to very high temperature, which produces an outer crust. When this has been removed the cubes are wrapped in paper and placed in the "drying stoves" at a lower temperature. The process of drying forms the familiar long white crystals. The fancy-box department is a distinct branch of the work, in which women and girls are mostly employed ; to provide for this, the firm has a large fancy-box making factory, and also a complete establishment for printing labels and other matter.

Blue.—When the firm commenced making this article, Ball Blue was a novelty and an immense trade was done in it, but this has gradually been superseded by the modern Square Blue, although quite a fair quantity of Ball Blue is still sold. A large export trade is done in this article.

Blacklead.—Very large quantities of blacklead are turned out daily, special machinery being employed for the purpose. The process of manufacture is not of a very clean nature, but the result is the production of a most brilliant form of blacklead for household purposes. The firm have obtained the highest awards at many international exhibitions. They have a branch business establishment in London, and employ a large number of hands.

MESSRS. WILLOUGHBY BROTHERS, ENGINEERING AND SHIPBUILDING WORKS, PLYMOUTH.

These works, established by Mr. William Willoughby in 1844, have gradually been extended, so that they occupy three distinct

sites, namely the main foundry and engine works at Rendle Street, a branch foundry in Phœnix Street, Stonehouse, and the shipbuilding yard which adjoins and extends nearly the whole length of the graving dock in the Great Western Docks.

Vessels have been built at these works for the Royal Mail Steamship Co., the Suez Canal Co., War Department, Customs authorities, and for the Corporation of the City of London, also ten vessels now running on the Thames and five on the Mersey. Chain ferries for Torpoint, Devonport, Saltash, Dartmouth, Littlehampton, and Felixstowe, and the ferry at Hythe in Southampton Water, were constructed and engined by this firm. Many of the pleasure steamers running in the locality were also built here. One of the firm's finest productions is the "Belle," a paddle-steamer built expressly for the Blackpool excursion traffic. The Admiralty have just placed an order with this firm for a steam water-tank vessel for service with the Channel Squadron.

PLYMOUTH PROMENADE PIER.

This pier was opened in 1884. It is 480 feet in length, and commands a fine view of the harbour. The pavilion is circular in shape, and has extensive interior and exterior balconies surrounding and enclosing its central dome. It is the largest erection of its kind in the kingdom, having accommodation for five thousand people. The concert season extends over the summer and autumn, two performances being given daily at three o'clock and at eight, and in winter the pavilion is given up to roller-skating, carnivals, confetti fêtes, &c. Sunday concerts are given all the year round.

DEVON GREAT CONSOLS MINES, NEAR TAVISTOCK.

These mines are situated on the Devonshire banks of the River Tamar, about five miles from Tavistock, which is one of the most picturesque inland towns of England. In 1844 a company was formed to develop further some old workings which had been abandoned for a very long period. A discovery of copper ore was quickly made, from which during the first twelve months' working over £70,000 profit was obtained; and by the end of the second year copper ore had been raised realising about £120,000. For many years afterwards the output steadily increased, and up to the 30th April last the following important results have been obtained from the minerals sold, namely copper ore realising £3,468,122 and arsenic £590,178. The dividends paid have amounted to £1,223,878, and the landlord has received in dues £279,679. The rich deposit of copper ore continued for nearly two miles in length, and to mine it profitably the sinking of eighteen shafts has been required, with about 45 miles of drivages at the various levels on the course of the mineral vein or lode. The cost of mining has been over two million pounds, and of plant over half a million pounds, on a capital of £20,000.

During the whole of the working of the mines a considerable quantity of arsenical mundic was found along with the copper ore. Up to about thirty years ago this was of little value, and as a consequence thousands of tons of it were thrown on the waste heaps. From these heaps and what has since been raised, over half-a-million pounds have been realised for arsenic, which is now the chief product of the mines. For the extraction of the arsenic from the mundic there are works covering about eight acres.

The motive power is chiefly water. There are five large water-wheels representing together about 700 horse-power; this power is used for draining the mines and for pumping water to the top of the hill, whence it is used on the various works until it finds its way back again to the River Tamar, but not before it has traversed about

eight miles of leats. There are also several steam-engines at work on the property; and a large portion of the machinery has been manufactured in the foundry and fitting shops on the mines.

Copper ore is not smelted on the mines of Cornwall or Devon, but, after being picked over and undergoing only a slight treatment, it is forwarded to the smelting works in South Wales. The preparation of arsenic is different, involving a long process. The arsenical mundic is reduced to the size of ordinary gravel at surface, and is placed in one end of a large iron-tube—about 30 feet long by 5 feet diameter—lined with fire-brick, about 7 to 18 inches from the horizontal. The tube is kept revolving by water-power. At the lower end of it there is a fire, and as the tube works around, a certain quantity of the arsenical mundic comes down to the fiery mass. When raised to a temperature of 356° Fahr. arsenic rises in vapour without undergoing fusion. The fumes that contain the arsenic are carried by draughts through a series of long flues that stretch up the side of the slope and end in a tall stack. At frequent intervals along the flue, walls are built half-way or more across, each alternate wall abutting from the opposite side. As the vapour cools it drops its burden of arsenic, and the plan is to place as many obstacles as possible in the way, in order that the whole of the arsenic may be caught before the stack is reached. Every chamber of the flue has a large door, and after the burning of the arsenical mundic has been going on for about a month, the fire is let out and the doors of the flue opened. There is then an incrustation of a greyish, crystalline substance about two or three inches thick on all the walls, and a thick body of soot on the bottom of the flue. This is scraped off, and, when the flues are closed up, burnt again. The arsenic again goes off in vapour, and is once more deposited in the flues. When the doors are opened again, the walls are covered with a substance like driven snow, that sparkles like myriads of diamonds. This is pure arsenic, a most deadly poison. When scraped off, it is ground into fine powder, and placed in barrels for exportation.

On the mines is a railway system, extending 5 miles, and two locomotives for taking the produce to the wharf at Morwellham.

Above the wharf is a steep incline, and a stationary engine at the top is employed in regulating the descent of the trucks loaded with copper or arsenic, and in bringing up others containing coal, &c., for use on the mines. Adjoining the wharf are ore-floors of several acres in extent, with a dock in the centre capable of accommodating six vessels of about 300 tons burden.

The resident manager, Captain William Clemo, has worked on the mines since they were started in 1844, and several of the officials have been there over fifty years. The number of workpeople is about 450.

COTEHELE HOUSE, CALSTOCK.

This house, which belongs to the Right Hon. the Earl of Mount-Edgcumbe, is a perfect example of the Tudor fortified mansion. It stands on a hill, and is surrounded by oak, ash, and chestnut trees. It is built around the quadrangle, one side of which is occupied by the hall, 44 feet long by 23 feet wide. There is an old chapel, with a leper's window, of simple architecture, which was erected at about the end of the fifteenth century by Sir Richard Edgcumbe, one of the ancestors of the present Earl. Having joined the Duke of Buckingham in 1468, during the Wars of the Roses, against Richard the Third, he was defeated and pursued by Sir Henry Trenoweth, but escaped by an artifice to the Continent. He then returned with Henry of Richmond, afterwards Henry the Seventh, and received from him the estates of Sir Henry Trenoweth. The chapel is his thank-offering for his escape.

MOUNT-EDGCUMBE PARK.

This Park is situated in Cornwall, two miles south-west from Devonport, on the opposite shore of Plymouth Sound. A steam-ferry leaves the Admiral's Hard, Stonehouse, at frequent intervals for Cremyll, which is within a hundred yards of the main entrance to the Park.

The gardens, near the Cremyll entrance, are adorned, like those at Chatsworth, with busts, fountains, &c., and are laid out in the Italian, French and English styles. They contain the ivy-clad ruin of an old castle, dating from the sixteenth century, at which time it played its part in the defence of the port. The cliff walks and drives are unequalled in beauty, and the mildness and equability of the climate are plainly demonstrated by the growth of tropical and sub-tropical shrubs and trees in wild profusion upon the south steep slopes of cliff. The views from the higher ground of the Park are very extensive and beautiful, extending as far as the peaks of Dartmoor. The Park is several miles in extent, and occupies nearly the whole of the peninsula to which the house gives its name. Among the objects of interest to be seen are the Amphitheatre, with its sloping sides covered by luxuriant firs, cedars, poplars, and other forest trees, and Milton's Temple containing a bust of the poet. From the Gothic ruin, perched on the brow of a commanding hill, a magnificent view of the Three Towns and their surroundings is obtained. Lady Emma's Cottage, the Great Terrace, Thompson's Seat, the Pavilion, the Zigzag Walks, and many other charming spots attract attention.

The House was built in 1553. It had originally a circular tower at each corner, but these have been made octagonal, and altered from time to time, so that but little of its original shape remains. The House, which is one of the residences of the Right Hon. the Earl of Mount-Edgcumbe, is not open to the public.

MUNICIPAL ELECTRIC LIGHTING WORKS, TORQUAY.

These works were formally opened on 17th March 1898, by the Ex-Mayor, Councillor T. Harrison. The supply for the first six months was given for evening lighting only, and the plant stopped at 1 a.m.; from September to December two shifts were arranged; from December 1898 the supply has been continuous, and with the exception of one transformer burn-out on 22nd December 1898, no hitch whatever has occurred.

The Provisional Order was obtained in 1891 by the late local board, but was not put into force until 1896 when Mr. W. .H. Trentham, of London, was instructed to report on the subject. Several schemes were submitted and considered, including a combination for electric lighting and refuse destruction, but owing to the large capital outlay required for buildings it was eventually decided to utilize some disused existing coal cellars under the Baths Saloons. Tenders were invited for the required plant, and the following firms accepted to carry out the work:—Messrs. Easton, Anderson, and Goolden, for engines, alternators and rectifiers, arc switchboard, steam and other piping, and condensing arrangements; Messrs. Babcock and Wilcox for boilers, feed-pumps, and economisers; Messrs. Ferranti for high-tension switchboard and rheostats; Messrs. Nalder and Hilton for transformers; the British Insulated Wire Co. for cables, arc-lamps and posts; and Messrs. Isles for overhead travelling-crane.

The system employed is high-tension alternate current at 2,000 volts, conveyed to transformers placed in pits under the pavements, whence it feeds the low-tension network at 200 volts. The periodicity of the alternators is 50 per second. The arc lighting is on the series system, supplied with rectified currents. A total of 52 Crompton-Pochin 12-ampère lamps is installed in the principal streets and round the sea front; three Ferranti 30-light rectifiers are employed, one being a spare as the lamps are arranged on two circuits. The arc posts are fitted with two 32 candle-power incandescent lamps which are lighted after the arc lamps are switched off, and are actuated by Edmund's automatic switch.

The boiler-house contains three Babcock and Wilcox water-tube boilers with a total heating surface of 4,857 square feet, fitted with superheaters and Granger's blowers for forced draught; the working pressure is 150 lbs. per square inch; a Green's economiser fitted with 192 4-inch pipes is also installed. The boiler feed-pumps, two in number, were made by the Worthington Co.

The main steam-ring and pipes are of lap-welded steel, with heavy wrought-iron flanges screwed on and brazed.

The alternators, three in number, of 150 kilowatts each, are of the inductor type with revolving fields, and all windings stationary, connected direct to Willans three-crank compound engines, which, at 375 revolutions per minute with a steam-chest pressure of 135 lbs. per square inch and a vacuum of 26 inches, deliver at the alternate shaft 250 I.H.P.

The main switchboard is of Messrs. Ferranti's usual type, consisting of twelve panels fitted with circuit fuse pots, ammeters, and synchronizer. The condensing plant consists of two Ledward ejector-condensers, supplied with sea-water by two compound steam-pumps, each capable of delivering 30,000 gallons of water per hour, a steady vacuum of 26 inches being obtained on all three engines. The borough electrical engineer is Mr. Percival Storey.

MEMOIRS.

Henry Wollaston Blake was born at 25 Portland Place, London, on 3rd March 1815, being the youngest son of Mr. William Blake, of Portland Place and of Danesbury in Hertfordshire, whose wife Mary was daughter and heiress of Mr. William Nash. He was named after his godfathers, Mr. Henry Warburton, and the celebrated chemist, Dr. Wollaston; his godmother was Mrs. Marcet, the authoress of many elementary scientific works. When eight years old he was sent to Rev. F. Faithful's preparatory school at Hatfield; and thence to Eton, where he remained for four years in the house of Rev. John Wilder. Whilst there he showed his early taste for mechanics by making a toy steam engine. On leaving Eton he travelled with his parents in France and Italy till October 1833, when he graduated at Trinity College, Cambridge, where he was elected a scholar, being first in mathematics, and first class in each of the yearly examinations. On taking the degree of master of arts in 1837 he came out fifteenth of the unprecedented number of fifty-two wranglers; but, as several names above his were bracketed equal, he practically ranked ninth. Methods and habits of business he learnt during a year spent in the house of Mr. Thomson Hankey, then Governor of the Bank of England, by whom he was deputed to accompany Mr. Cowell, the agent of the Bristol branch of the bank, to America, as his assistant secretary, to aid him in collecting £5,000,000 worth of protested bills held by the bank, in consequence of the failure of three large American houses of business during the monetary crisis then prevailing. For eighteen months he was constantly employed in travelling through America—no easy matter in those days—to collect the various securities, then generally given on slaves. During this time he became acquainted with President Webster, Clay, Van Buren, Colquhoun, and other noted Americans. When on the point of returning to England a curious incident saved

his life. The two steamships, "Great Western" and "President," were both at New York; and having endeavoured unsuccessfully to secure a berth in the former, which was the first to sail, he took one in the latter. But on the same evening, happening to meet Mr. Power, the actor, who had taken a berth in the "Great Western" and wanted to stay on for a fortnight to act in New York, he offered to change with him, and consequently sailed that night, while Mr. Power sailed a fortnight later in the ill-fated "President," which was never heard of afterwards. Soon after his return to England he became in 1841 a partner in the firm of James Watt and Co., of Soho Foundry, Birmingham, and by his commercial ability, energy, and influence, aided in restoring the fortunes of the place. After the death in 1846 of Mr. James Watt, the son of the great James Watt, he remained the head of the firm for nearly fifty years, during which period they were responsible for such engineering works as the following:—pumping engines for waterworks in Italy, Turkey, Siam, Japan, Straits Settlements, Hong Kong, Brazil, Vancouver's Island, Moscow, Warsaw, Hamburg, York, Birmingham, Bristol, London; also pumping engines for the Metropolitan drainage, London docks, the royal dockyards, principal London breweries, and for the drainage of the fens; many large marine and stationary engines, including the oscillating engines of the Dublin mailboats which ran for thirty years; also in conjunction with Brunel and Scott Russell the screw-engines of the "Great Eastern" steamship, whose trial trips he accompanied with Brunel. For the latter engineer they were concerned too with the mechanical details of the atmospheric railway. Mint machinery in large quantities was supplied from Soho to the Royal Mint, as well as to those in Bombay, Madras, Calcutta, Japan, Mexico, Chili, Constantinople, and St. Petersburg. A large mint was erected at Soho by his firm, where the bronze money for Japan and Siam was coined, as well as 2,000 tons of the new bronze coinage of the United Kingdom. In 1845 he became an Associate Member, and in 1879 a Member, of the Institution of Civil Engineers; and was elected a Member of this Institution in 1862. In 1843 he was elected a Member of the Smeatonian Society of Civil Engineers, and also a Fellow of the Royal Society; of the

former he was the President in 1858, and of both he was the "father" at the time of his death. Of science in all its branches he had an increasing love, especially of astronomy; even as lately as in 1896 he accompanied with his wife the expedition to Vadsö in Norway for observing the total eclipse of the sun, and was requested by the Royal Astronomer of Dublin to publish his notes on the variations of temperature during the eclipse. He was a Member of the British Astronomical Association, and for many years a Fellow of the Royal Geographical Society, a Member of the Royal Institution, and of the British Association. For forty-nine years he was one of H.M. lieutenants of the city of London, and for forty-six years a director of the Bank of England. When the question of bimetallism arose about 1881, on which each director was requested by the governor to write his opinion, so clear and comprehensive was his letter that he was selected by the bank to go before the commission of the House of Commons appointed to consider the matter. It was also on his evidence that the scheme for removing the Royal Mint from its present position to the Thames Embankment was abandoned; and Mr. Gladstone wrote acknowledging the assistance rendered by him on this proposal. In 1861 he travelled in Russia with Mr. Hugh Childers, in connection with the establishment in Bulgaria of the Varna and Rustchuk Railway between the Danube and the Black Sea; of this line he was chairman for twenty-five years, and in 1888 was instrumental in carrying through the negotiations for its purchase from Turkey by the Bulgarian government. Of the Grand Trunk Railway in Canada he was long a director; and from 1842 of the London & North Western and Stour Valley Railways. By a curious coincidence he was at the same time offered a seat on the Great Western Railway board; but as the London and North Western Railway passed Birmingham, and the Great Western at that time did not, he chose the former, and was placed upon the locomotive committee. In this capacity, having on Mr. Bessemer's invitation witnessed nearly the first castings from his early crucible, he supported the erection of the steel works and rolling mill at Crewe, and the adoption of the Bessemer process there. At various times he held numerous other directorships, notably those of the Atlantic

Leased Lines, the British Plate Glass Consolidated Trust, the Incandescent Gas Light, the Great Indian Peninsula Railway, the Indian Midland Railway, and the Continental Union of Gas. He died on 27th June 1899 in his eighty-fifth year at his residence, 8 Devonshire Place, London, after a few days' illness of pneumonia. His decease removes another link with a great past in the engineering world, and a familiar figure in social and business circles. He was twice married: first to Charlotte, daughter of John Walbanke Childers, of Cantley, near Doncaster, who left him two surviving sons; and secondly to Edith F., daughter of Rev. Prebendary Hawkshaw, of Weston-under-Penyard, near Ross.

David Jollie Brand was born at Causewayhead, near Stirling, on 14th May 1852. After being educated at Greenock he served his apprenticeship from 1867 to 1872 in the Kilblain Engine Works of Messrs. John Hastie and Co., Greenock. Thence he went to London, and from 1872 to 1874 was foreman of the machine shop in the sewing-machine works of Messrs. J. G. Weir and Co. From 1874 to 1882 he was a marine engineer in the service of the Peninsular and Oriental Steamship Co., and obtained a first-class certificate of the Board of Trade; during two years of this period he was second engineer of the s.s. "Assam." From 1882 to 1883 he was chief engineer of a sugar plantation at Rockhampton in Queensland. In 1883 he became a partner in the firm of Messrs. Brand and Drybrough, Cleveland Foundry and Engine Works, Townsville, Elphinstone County, North Queensland, who were engaged from 1885 to 1891 in constructing the breakwater of Townsville harbour as sole contractors; they had also a slipway for hauling up ships for repairing. His combination of business shrewdness, intellectual ability, physical energy, and power to influence his fellow men, marked him out as one destined to do good work for many years. He was in the best of health when on 26th October 1897 he went on board a dredge which his firm had working at a government contract for dredging the Gladstone Narrows, and was suddenly taken ill and expired, at the age of forty-five. He became a Member of this Institution in 1892.

Ernest Dutch was born in Manchester on 9th August 1866. In 1879–83 he received his education at the Manchester Grammar School; and in 1883–88 served his apprenticeship with Messrs. Sharp, Stewart and Co., whose works were then in Manchester. Afterwards he had several engagements as practical engineer as well as draughtsman with firms in Manchester and neighbouring towns; from 1889 to 1893 as draughtsman with Mr. W. F. Cheetham, and as draughtsman and general assistant with his son. In 1893 he went as draughtsman to the Standish Bleach and Dye Works at Worthington, near Wigan, where his services were held in high estimation, and he rose to the position of superintendent engineer. In connection with the work of this firm he invented several improvements, particularly one for producing a fine spray of liquid for damping fabrics; also a steam trap for high pressures. He died of acute pneumonia on 17th July 1899 in the thirty-third year of his age. He became an Associate Member of this Institution in 1899.

James Evans Griffiths was born at Llangibby, near Newport, Monmouthshire, on 18th April 1846. He commenced serving his time as an engineer in the Great Western Railway shops, Swindon, under Mr. John V. Gooch, in September 1861, and remained there until March 1865, when he went to Cardiff to complete his apprenticeship in the Taff Vale Railway works under Mr. Joseph Tomlinson, where he served until April 1867. During this period he was employed in the various shops, both repairing and building engines, and also for some time in the drawing offices. On the expiry of his apprenticeship, he continued in the same employ as journeyman until April 1868; and then joined a steamship as engineer, and remained at sea until May 1873, serving in the position of second and afterwards of chief engineer. Having obtained a first-class certificate, in May 1873 he joined Messrs. Lace and Son, engineers, Cardiff, until May 1878, when he started in practice as a consulting engineer at Cardiff, and latterly was senior partner in the firm of Messrs. Griffiths and James, Cardiff. His death took place there on 15th July 1899 at the age of fifty-three. He became a Member of this Institution in 1884.

John Condie Wylie was born in Glasgow, in the district of Hutchestown in the parish of Govan, on 2nd January 1853, being a son of Mr. Allan C. Wylie, engineer. After receiving his early education from 1861 to 1868 at Arnold House, Hackney, London, he served his time from 1868 to 1873 with Messrs. J. and H. Gwynne, Hammersmith Iron Works, London, working his way through all departments. He was afterwards employed in the workshops of Mr. John Stewart, Blackwall; Messrs. A. Chaplin and Co., Glasgow; the London and Glasgow Engineering Co., Glasgow; and for six months was draughtsman with Messrs. A. Ransome and Co., Chelsea. From 1875 to 1880 he was engineer to the London and South African Exploration Co., who owned a diamond mine situated in Dutoitspan near Kimberley, Cape Colony, where he was personally acquainted with Mr. Rhodes, Dr. Jameson, and others since famous, but was not associated with their doings. After a visit to England he became engineer and manager 1880–85 to the Standard Diamond Mining Co. and the Compagnie Générale, Kimberley. Revisiting England in 1886, he then went to the Transvaal, and from 1886 to 1894 was engineer and general manager to the Lisbon-Berlyn Gold Mining Co., Lydenburg, for whom during his stay of seven years he was the means of acquiring the Frankfort mine, the only paying mine they possessed. After another visit to England he went to the West Coast of Africa to manage the Appantoo Gold Mining property, and thence to Western Australia to investigate the Bamboo Creek property, whence after nine months' stay he sailed for England in the "China," aboard which he was a passenger when she was wrecked. In 1897 he undertook the management of the Wassau Gold Mining property, Gold Coast, but becoming ill of fever was compelled to return home in December 1898. Believing he had completely recovered, he went out again to the Gold Coast to resume his duties there; but in time the fever again attacked him and necessitated his return. He reached home on 31st July, and died on 8th August 1899 at St. Ives, Cornwall, at the age of forty-six. He became a Member of this Institution in 1895.

The Institution of Mechanical Engineers.

PROCEEDINGS.

October 1899.

The October Meeting of the Institution was held at Storey's Gate, St. James's Park, London, on Friday, 27th October 1899, at Eight o'clock p.m.; Sir William H. White, K.C.B., LL.D., D.Sc., F.R.S., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and the following fifty-nine candidates were found to be duly elected :—

MEMBERS.

Alley, Stephen Evans,	Glasgow.
Andrew, George Edward, R.N.,	Channel Squadron.
Bailey, William Seybourne,	Hong Kong.
Banks, George,	Manchester.
Beswick, Frederick Arrowsmith,	Manchester.
Bowman, Harold,	Preston.
Burcham, Richard Edward,	Manchester.
Campbell, Robert Malcolm,	London.
Carnt, Edwin Charles,	Cowes.
Feetham, Mark,	London.
Gibson-Sugars, John Sugars, R.N.,	Chatham.
Hacking, William Henry,	Bury, Lancs.

Hedley, Robert, ...	Spennymoor.
Hiller, Henry King, . . .	Shanghai.
Holden, Robert, ...	London.
Jackson, Sir John, F.R.S.E., . .	London.
Lonnon, William, R.N., . .	Devonport.
Meaden, Nicholas, R.N., . .	Rochester.
Oliver, Thomas, ...	Manchester.
Orcutt, Harry Fred Lee, . .	Berlin.
Ottewell, Albert, . . .	Derby.
Roberts, David, ...	Grantham.
Sargeant, Edward Frank, . .	Stroud, Glos.
Sibbering, George Thomas, . .	Cardiff.
Thorburn, William, . . .	Bilbao, Spain.
Vernon, Charles Edward, . .	London.
Woof, Thomas, ...	London.
Wotherspoon, James Douglas, .	Middlesbrough.
Young, Thomas, ...	Glasgow.

ASSOCIATE MEMBERS.

Burt, Thomas Ross, . . .	Sydney.
Corrie, John Bradford, . .	London.
Fox, Frederick Joseph, . .	London.
Garbutt, Henry, . . .	Birmingham.
Hildage, Henry Thomas, . .	Manchester.
Hitchins, Charles Faunce, . .	London.
Humphreys, William Henry, .	York.
Joyce, Thomas Walter, . .	Scarborough.
Kempt, Alfred Rodney, R.N., .	Mediterranean Fleet.
Kensington, John Charlton, .	Astillero, Spain.
Lash, Horatio William, . .	Sheffield.
Osburn, George Victor, . .	Gibraltar.
Powrie, William Lyall, . .	London.
Redding, Walter, . . .	Leeds.
Roberts, Percy Roper, . .	Salisbury, S. Africa.
Sirri, Lieutenant M., . . .	Constantinople.
Wheeler, Oswald, . . .	London.

ASSOCIATE.

Young, John Drummond, . .	Glasgow.

GRADUATES.

Bower, Henry Allan Richard, .	Rhodesia.
Cooke, Rupert Thomas, Jun., .	Liverpool.
Cotton, George Burchell, . .	Torquay.
Davis, Harry Charles, . .	London.
Griffiths, Harold, . . .	Wolverhampton.
Hawkins, Elyot Sydney, . .	Oswestry.
Philpot, Harold Percy, . .	London.
Pointon, John Edward, . .	Wellington, Salop.
Pritchard, Roger Cromwell, .	London.
Stow, George, ...	Brighton.
Tarling, Thomas, . . .	Morro Velho, Brazil.
Thomson, Alfred Morris, . .	Dundee.

TRANSFERENCES.

The President further announced that the following four Transferences had been made by the Council since the Spring Meeting:—

ASSOCIATE MEMBERS TO MEMBERS.

Bennis, Alfred William, . .	London.
Blaxter, Augustus Pearce, Jun., .	London.
Pritchard, Hugh, . . .	Port Dinorwic.

ASSOCIATE TO ASSOCIATE MEMBER.

Kitto, William Henry, . .	London.

The President then said that, before calling upon Mr. Ingham to read his Paper, he wished to say a word or two on the subject of the altered arrangements for the meetings of the Institution which had been announced on the cards issued to the members. The feeling of the Council was, that having entered into their new house they ought to make full use of it, and that a good beginning would be made by arranging Monthly Meetings throughout the winter. That evening was the first of these meetings, and it had been decided on the whole to be the best plan to have only single evening meetings rather than two or three evenings in succession, as had hitherto been the custom. On analysing the reports of attendances at past meetings, it had been found that while they generally had a good attendance on the first of three evenings, the numbers gradually diminished on the second and third evenings. Therefore it was thought in every way more convenient to the members that they should have single evening meetings. Should the discussion on any Paper on any particular evening go beyond the limit of time available, there would be no difficulty in postponing the discussion, and it was possible that in that way better discussions would be secured, than if they proceeded from evening to evening, because there was always the possibility of revising or re-considering notes which had been made. Some of the members might come to the conclusion, after hearing a portion of the discussion, that they had better vary their criticism from that which they had at first intended to offer. In any case the Council had taken that course after a most careful and thorough discussion, and now appealed to the members of the Institution to help them to make the coming session one of the most successful they had ever had. They would of course announce from time to time the subjects of the Papers to be taken on a particular evening, and they hoped to continue the excellent practice which had hitherto obtained of circulating printed copies of the papers to the members beforehand, in all cases where it was possible.

With reference to the Graduates' Meetings, which they hoped to commence on the following Monday evening, he appealed to all members of the Institution to help that new departure by every means in their power. The Council was quite sure that the future

success of the Institution depended in no small degree upon the success which might attend the meetings of the graduates section. They wanted those meetings to be true meetings of the graduates. A Committee had been formed of the graduates, and it was the desire of the Council that the graduates should manage their own affairs as far as possible, but encouragement, assistance, and occasional attendance on the part of the members of the Council and of the Institution would no doubt do very much towards securing that success which they all desired.

The following Paper was read and discussed :—

"The Incrustation of Iron Pipes at the Torquay Water Works"; by Mr. William Ingham, *Member*, Borough Water Engineer.

The Meeting terminated at a Quarter to Ten o'clock. The attendance was 118 Members and 101 Visitors.

THE INCRUSTATION OF IRON PIPES AT THE TORQUAY WATER WORKS.

By Mr. WILLIAM INGHAM, *Member*,
Borough Water Engineer.

The water-supply to Torquay, Newton Abbot, St. Mary Church, and Cockington, is obtained from a tributary of the River Teign which rises in the granite hills on a western spur of Dartmoor. Two storage reservoirs, containing 297,000,000 gallons, have been constructed there, and the water is conveyed by two cast-iron mains to Torquay; the old main laid in 1858 is 14 miles in length, and was first scraped in 1866. It is 10 inches in diameter as far as Newton Abbot and 9 inches forward to the foot of Chapel Hill, where it is reduced again to 8 inches between that point and the service reservoir. This main was not coated with any protective material, and within twelve months of being laid began to show signs of corrosion. Dr. Angus Smith's coating was unknown at the time the pipes were laid, and no one thought that the pure water from the Dartmoor hills would cause such a quick and deleterious action on the pipes. It was, therefore, with considerable surprise that at the end of eight years the delivering power of the mains should be reduced to 51 per cent. of their full discharging capacity.

A report was then submitted by the engineer, Mr. Easton, and the question of taking up the pipes in $\frac{1}{4}$-mile sections and coating them was considered, but as this was thought to be too expensive some other way out of the difficulty had to be found. It was at this period that Mr. Appold was consulted, and the idea of sending a scraper through the main was first suggested, and being accepted, he received instructions to have a scraper made. The outcome of this

was the scraper shown in the photograph, Fig. 1, Plate 131. The subsequent improvements, Figs. 2 and 3, were due to Mr. Box and Mr. William Froude, and the scrapers have not been altered since 1873. The scraper now in use, Fig. 3, was described and fully illustrated by Mr. Little at the Penzance Meeting.* It is therefore unnecessary to give a full description of the machine, but only just sufficient to give some idea of its construction.

The 10-inch scraper, which is 3 feet 8 inches in length, consists of two parts, the front portion being the knives and springs supported by a framework, and the rear of two pistons. These pistons are made of brass and are about 1 inch less in diameter than the pipe. Immediately behind these pistons are leather discs strengthened by segmental iron plates; they are made rather larger than the diameter of the pipe, and the pressure of the water acting on them propels the machine forward. The rear part of the scraper is connected to the front by a swivel joint which has a considerable amount of play so as to pass round curves easily. Just in front of the joint there is a cylindrical guard formed of flexible steel segments, which protects the piston leathers. The steel knives are four in number, and are kept in position by steel springs. From the nose of the scraper four pieces of steel project backwards, which serve to keep the scraper concentric with the pipe. The knives press outwards against the inside of the pipe with a force of about 48 lbs., and having a backward as well as a radial motion, they give way on meeting a projection which causes a pressure on the point of the knife of 60 lbs.

The knives are rather more than one-fourth of the circumference in length, and are in pairs diametrically opposite to one another, one pair being about $4\frac{1}{2}$ inches in advance of the other; they are V shaped and the scraper moves bodily round if they meet with a ferrule or anything of that kind. The two pistons already referred to are placed at such a distance apart that they will cover the largest hole of any branch pipe from the main, otherwise the water would rush past the pistons and cause the scraper to stop. The force required to drive a 10-inch scraper at Torquay is from 350 to 400 lbs.,

* Proceedings 1873, page 216.

or about 5 lbs. per square inch behind the scraper. But for the smaller scrapers the pressure per square inch required would be greater, because the ratio of the figures representing the area of a small pipe compared with its circumference is less than in the larger sizes. For instance, comparing a 6-inch with a 10-inch, the area of a 6-inch is 28·3 square inches, and the circumference is 18·86 inches, while the corresponding dimensions of a 10-inch are 78·6 square inches, and 31·4 inches respectively. The ratio of these figures, representing the area and the circumference in a 6-inch pipe, is nearly $1\frac{1}{2}$ to 1, and in the 10-inch pipe $2\frac{1}{2}$ to 1. As already stated, a force of 400 lbs. would move a 10-inch scraper, this representing a pressure of 5·1 lbs. per square inch behind the scraper. Then—

$$5\cdot1 \times \frac{18\cdot86}{31\cdot4} \times \frac{78\cdot6}{28\cdot3} = 8\cdot5 \text{ lbs. per square inch}$$

would put the 6-inch scraper in motion, if the rust was similar in both cases. At the Torquay Water Works the scraper is inserted where the head due to water is only 3 feet, but when the wash-out pipe in front is opened a partial vacuum is created, and the actual head is then 3 feet plus the difference between the atmospheric pressure and the pipe pressure in front of the scraper. Where scraping is necessary it is not advisable to have the radii of curves in the pipe line under 30 feet, although in well-proportioned scrapers fifteen times the diameter of the pipe will be sufficient. For pipes under 5 inches diameter water-pressure scrapers cause considerable trouble and do not act very well. In laying pipes which will eventually require scraping, it is recommended that the pipe jointing be carefully watched to see that no lead finds its way into the pipe. Stones, chisels and rubbish of all kinds are taken from newly scraped mains, and cause considerable annoyance and trouble before the wash-out or hatch-box is reached. Before scraping is commenced, pipes and double collars should be placed alongside the main, in case the scraper sticks and the pipe has to be cut out: cutting tools, spades, picks, lead, yarn, fire-basket, hand-pump, and a full complement of pipe-laying tools should accompany the men when scraping.

TABLE 1.—*Summary of Scraping Water Mains by Water Pressure.*

Year.	Name of Place.	Diam. of Main.	Length of Main.		Total Cost.	Cost per yard.	Obstructions.	Gain in delivery after Scraping.
		Ins.	Miles	Yds.	£	*d.*		Per cent.
1877	Oswestry *	7 6	1 4	440 660	121	2·93	Large stones, lead, and defective pipes	54·4
1878	Lancaster	8	1	1,500	30	2·2	Peaty matter	56·1
1880	Durham *	12	1	586	91	9·1	Lead, spade, hard spike, and wagon spring	—
1880	Bradford *	18	4	1,100	634	18·6	Stones, lead, crow-bar, &c.	55·6
1881	Halifax, N.S.†	12	1	573	91	9·3	—	—
1882	Exeter	10 12	2 2	0 0	192	6·5	—	—
1883 1885	Whitehaven *	13 11	2 3	1,056 1,232	516	11·1	Mussels, stones, and lead	27·6
1885	Bristol	6	1	785	35	3·3	Stones	—
1886	Denbigh	6	1	880	150	13·6	Stones, gravel, and lead	—
1887	Omagh	6	2	792	53	2·9	Lead and defective castings	300·0
1887	Halifax	6	0	776	21	6·5	—	—
1888	Ulverston	6	1	0	72	9·8	—	—
1890	Dundee	15	2	0	256	17·4	Wood and stones	—
1890	Dumfries	9 8	1 4	0 0	113	3·0	Stones	—
1890	Scarborough	8	1	440	62	6·7	—	—
1891	Newport	10	0	1,080	50	11·1	Lead	—
1891	Lanark	7	6	880	75	1·57	Lead, wood, and stones	33·7
1891	Guisborough	6	1	0	36	1·84	—	—

* These scraping operations were carried out by the Glenfield Co., Kilmarnock. † Test made by Mr. Keating, of Toronto.

TABLE 1—(*continued to next page*).

Year.	Name of Place.	Diam. of Main.	Length of Main.		Total Cost.	Cost per yard.	Obstructions.	Gain in delivery after Scraping.
		Ins.	Miles	Yds.	£	*d.*		Per cent.
1891	Newport	5	0	75	8	—	—	—
1892	Roubaix,* France	24	5	594	242	6·1	—	16 feet head taken off pumping engine
1892	Burntisland	8	3	1,320	252	9·02	Piece of Wood 2 ft. 3 in. by 5 in. by $5\frac{1}{2}$ in., lead ($4\frac{3}{4}$ lbs.), and stones	43
1893	Bridge-of-Allan	6	1	0	—	—	—	35
1893	Thurso	6	3	0	—	—	—	7
1894	Stirling	8	3	1,320	—	—	Stones, lead, and piece of broken pipe	—
1894	Inverkeithing	5	2	880	—	—	Lead	—
1894	Waterford	13	8	0	211	3·11	Pieces of broken pipe, rope	40
1895	Cupar, Fife	7	3	880	67	2·6	Piece of broken pipe, rabbit	52
1895	Merthyr Tydfil	14	5	617	318	8·01	About 400 stones	30
1896	Cowdenbeath	6	3	1,405	90	3·26	Lead	23
1896	Merthyr Tydfil	12	6	770	178	3·76	Pieces of broken pipe, lead and stones	82
1896–7	Kendal	6	1	1,430	54	4·08	Lead, rust, and peaty matter	—
		4	0	830	22	6·32	Rust and peaty matter	—
† Yearly, commenced in 1866	Torquay	10 & 9	14	0	—	0·1	Rust in the form of nodules	28
1896	Torquay	10	15	0	21	0·2	35 lbs. of lead, stones, &c.	28·5

* Test made by French engineers.

† The total cost of the scraping in 1866–7 was no less than £1,200.

TABLE 1.—*Summary of Scraping Water Mains by Water Pressure* (*concluded from page* 482).

Additional information supplied subsequently by Mr. John Barr, *Associate*, of Kilmarnock.

The following scraping operations, with two exceptions, were carried out by the Glenfield Co., Kilmarnock.

Year.	Name of Place.	Diam. of Main.	Length of Main.		Total Cost.	Cost per yard.	Obstructions.	Gain in delivery after Scraping.
		Ins.	Miles	Yds.	£	*d.*		Per cent.
1897	Dalkeith	5	3	0	No record	No record	Pieces of pipes, bad joints, lead, &c.	75
1897	Campbeltown	6	0	854	24	6·68	Scraper stuck hard against plug in angled branch	About 25 lb. of pressure.
1897	Alfreton	7	4	0	57	1·39	Pieces of cast-iron pipe and stones	30
1897	Cumnock	5	1	880	52	3·52	Bad lead joints, stones, &c.	50
1897	do.	6	0	912				
1897	Bishopton	2½	0	138	10	18·00	(Hand-scraped) pipes completely choked	Delivered 12 gals. per minute after scraping.
1897	Waterford (second scraping)	13	7	0	29	0·45	Piece of pipe 9 ins. by 5 ins. 5–8ths in.	50
1897	Bredbury and Romily	6	2	0	31	2·08	Lead	Pressure increased by 10 lbs.
1898	Kirriemuir *	6	6	0	78	1·78	Bad joints	75
1898	Rothesay	16	1	440	No record	No record	—	Pressure increased by 33½.
1898	do.	14	2	440				
1898	Montrose †	11 & 12	2	704	11	0·62	—	No Record.
1899	Bingley	9	0	1,268	92	17·50	—	86
1899	Bangor, Ireland	7	2	0	No record	No record	Stones	50
1899	Dunfermline	12	14	0	270	2·63	Pieces of lead (one weighing 12½ lbs.) and stones	30
1899	Plymouth	24	1	880	300	27·27	—	3 million gals. daily.
1899	Tobermory, Mull	6 & 3	0	164	No record	No record	(Hand-scraped)	No record.
1899	Bridge of Allan	5	0	245	No record	No record	—	Pressure greatly increased.

* Test made by Mr. George Baxter, of Dundee. † Test made by Mr. H. Hall, of Montrose.

The approximate cost of scrapers, hatch-boxes, and wash-outs, may be taken as follows:—

	10-inch. each.			6-inch. each.			4-inch. each.		
	£	s.	d.	£	s.	d.	£	s.	d.
Scraper complete . .	23	0	0	10	10	0	1	15	0
Hatch-boxes . . .	6	6	0	4	0	0	2	0	0
Wash-outs . . .	5	0	0	3	10	0	2	10	0

A 6-inch wash-out will be quite sufficient for a 10-inch main, a 4-inch for a 6-inch, and a 3-inch for a 4-inch. The 4-inch scraper would be of the Kennedy pattern. It is difficult to give the price of scraping any main without knowing the full particulars of the pipe line, but the list of tests on pages 482 and 483, made for the most part by the Glenfield Co. of Kilmarnock, and taken from Mr. Barr's Paper* on the "Scraping of Water Mains," will be of interest. The cost of scraping at Kendal and Torquay have been added, but in the latter case the cost is that for labour only, Table 1, page 483. In comparing the cost of scraping, the length of the main should be taken into consideration, for it will be found cheaper to scrape long pipe lines than short ones. If the pipe is an uncoated one a greater force will be required to remove the nodules than in the case of those which are coated. The first scraping will also be found more difficult than the subsequent ones, and, once commenced, the pipes require scraping afterwards at short intervals. At Torquay this is done on both trunk mains every year, and the delivery is increased about 28 per cent. even after such a short period. The scraper can be easily followed, when the mains are about 3 feet deep, by the rumbling noise it makes; there is a considerable variation in the sound made when passing over different classes of strata, but the men soon get used to it. As a rule seven men take part in the scraping at Torquay, and these are placed 20 or 30 yards ahead of one another, and run along as the machine progresses. The reason of so many men being required is owing to the variations in the speed of

* Transactions, Institution of Engineers and Shipbuilders in Scotland, 1896–97, vol. XL, page 201.

the scraper, for if it rushes past any one or two of them, the next man ahead locates it. If the scraper is lost there is considerable trouble in finding it again, so it pays to have a few extra men about to avoid losing it; and, moreover, if the scraper sticks they are required to excavate and cut out the pipe. If the scraper stops, it is usual to open the last wash-out and then shut it quickly; the impetus thus obtained often carries it past the impediment, but care should be exercised to see that the ram action is not too great to force the pipe joints or to burst the pipes; should this be unsuccessful a wisp of hay may be inserted, which makes practically a water-tight piston, and thus increases the pressure on the scraper. If this fails, then tapping the main with a hammer where the scraper has stuck sometimes causes its release. When the above methods have been tried and end in failure, the only course is to cut out the pipe. If it is desired the scraper can be examined at any hatch-box by inserting an iron cup to catch it. If after examination it is found in good condition, the hatch-box cover is bolted down again and the work recommenced. Where wash-outs are necessary in towns they are usually connected with the sewer, and if this is done it is advisable to trap the sewer and construct a brick pit, with a ventilating grating so as to allow the escape of sewer gas if the water of the trap is evaporated.

A section of the old main from Tottiford intake to Torquay is shown on Plates 132 and 133. The depth of the pipe under ground is about 3 feet, except for a distance of about 180 feet, where it increases to 18 feet at the deepest point. The difference in head between the intake at Tottiford and the lower or Chapel Hill service reservoir is 468 feet, and the average gradient 1 in 157. The first hatch-box is placed at Knowles Hill about 8 miles from the intake and the second one at the foot of Chapel Hill, at Torquay, nearly 6 miles further on. Wash-outs are placed at the bottom of all valleys, and the speed of the scraper can be regulated by opening or shutting down the valve. The scraper moves quicker when on a down grade than it does on an up grade, and this is due to the weight (132 lbs.) of the scraper and water. Air-valves are placed on most of the elevations, and it may be of interest to know that these have a considerable effect on

the speed of the scraper; these ought to be shut off when the scraping is in hand because the air rushes in when the water is withdrawn from the pipe, and instead of a partial vacuum we get the atmospheric pressure against the scraper. These air-valves were fixed in 1897, and since then the amount of corrosion has decreased somewhat; this is probably due to the gases escaping instead of being carried along by the water.

The cost of scraping the old main is about £10, and works out at one-tenth of a penny per lineal yard. This is a very low figure, and is perhaps the cheapest piece of scraping in the country. The men engaged are thoroughly in touch with the work, and no difficulty is experienced in following the scraper at any part of the line, except for about 180 feet where the pipe is about 18 feet below the surface of the ground. The scraping is done during the day, but where the line passes through Newton Abbot operations are commenced early in the morning, before much traffic is on the road. It is very exciting to follow the scraper over hill and dale, and especially so if the wash-out pipe in front has been fully opened. A speed of $7\frac{1}{2}$ miles per hour can be obtained for about $\frac{3}{4}$ of a mile on one part of the line.

Table 2 on page 488 gives the discharges before and after scraping.

The theoretical delivery of the old main is 595 gallons per minute according to Box, and is calculated by the formula:—

$$G = \left\{\frac{(3 \times D)^5 \times H}{L}\right\}^{\frac{1}{2}}$$

Prony's formula:—

$$G = \left[\left\{\left(\frac{16 \cdot 353 \times H \times d \times 0 \cdot 00665}{L}\right)^{\frac{1}{2}} - 0 \cdot 0816\right\} \times d^2 \times 2 \cdot 04\right]$$

gives 616 gallons per minute.

Eight years after the pipes were laid the delivery was only 317 gallons, or 51 per cent. of Prony's delivery, the head lost being about 351 feet. The present delivery after scraping is 708 gallons per minute, or 92 gallons more than given by Prony's formula.

This increase can only be accounted for by the corrosion of the main itself, and as the delivering power of a main varies as the $2 \cdot 5$ power of the diameter when head and length are constant, the main

must have been enlarged from 10 inches to $10\frac{1}{2}$ inches diameter in forty-one years.

After twelve months it is found that the nodules are about $\frac{1}{8}$ to $\frac{3}{16}$ of an inch in height, but the effect is such that the 10-inch pipe has only a delivering capacity of a 9-inch one. This is due to the eddies developed in the water by the nodules and also to the much larger surface exposed to friction. For instance, taking a pipe 10 inches in diameter which is covered with nodules as shown on the pipe-section, Fig. 4, the surface exposed to friction would be approximately 35 inches, whereas the circumference of the pipe would only be 31·4 inches, the increase being about 11 per cent. Working out the cubic contents of the nodules as shown on the section it is found that

TABLE 2.—*Delivery before and after scraping Torquay Water Mains.*

Year.	Old main laid in 1858. Delivery in gallons per minute. into Chapel Hill Reservoir.		New main laid in sections 1878 to 1891. Delivery in gallons per minute.	
	Before scraping.	After.	Before scraping.	After.
	Gallons.	Gallons.	Gallons.	Gallons.
1866	317	454		
1867	—	564		
1868	—	624		
1869	423	659		
1870	471	668		
1871	496	684		
1872	499	681		
No records.				
1896	550	698	516	663 Delivery into Warberry Reservoir.
1897	600	693		
1898	586	708	705	835 Delivery into Chapel Hill Reservoir.
1899	590	698		

Iron-pipe Scrapers.

Fig. 1.
Appold.

Fig. 2.
Box and Froude.

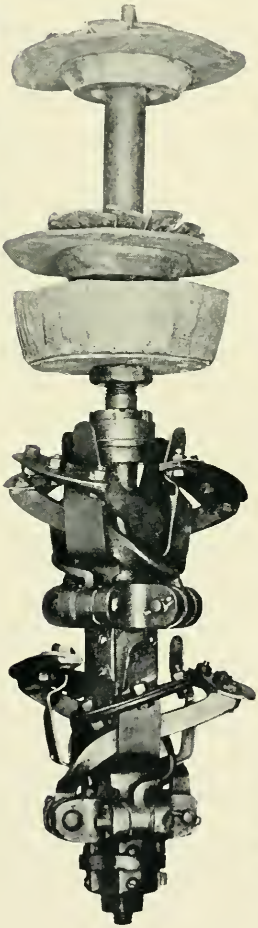
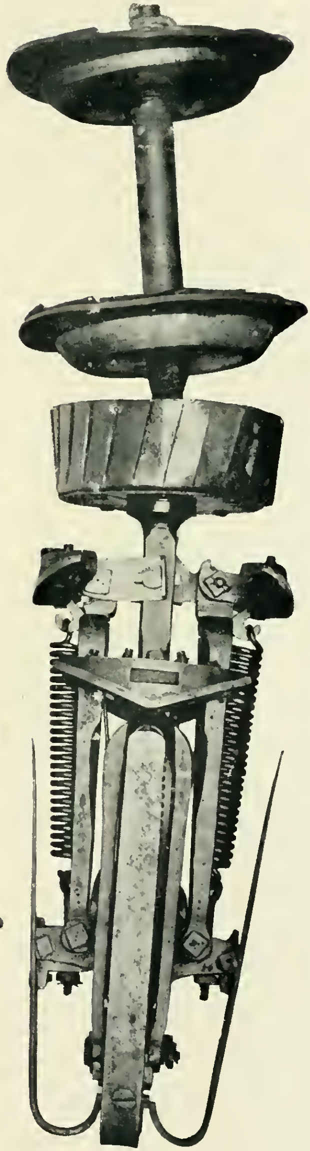
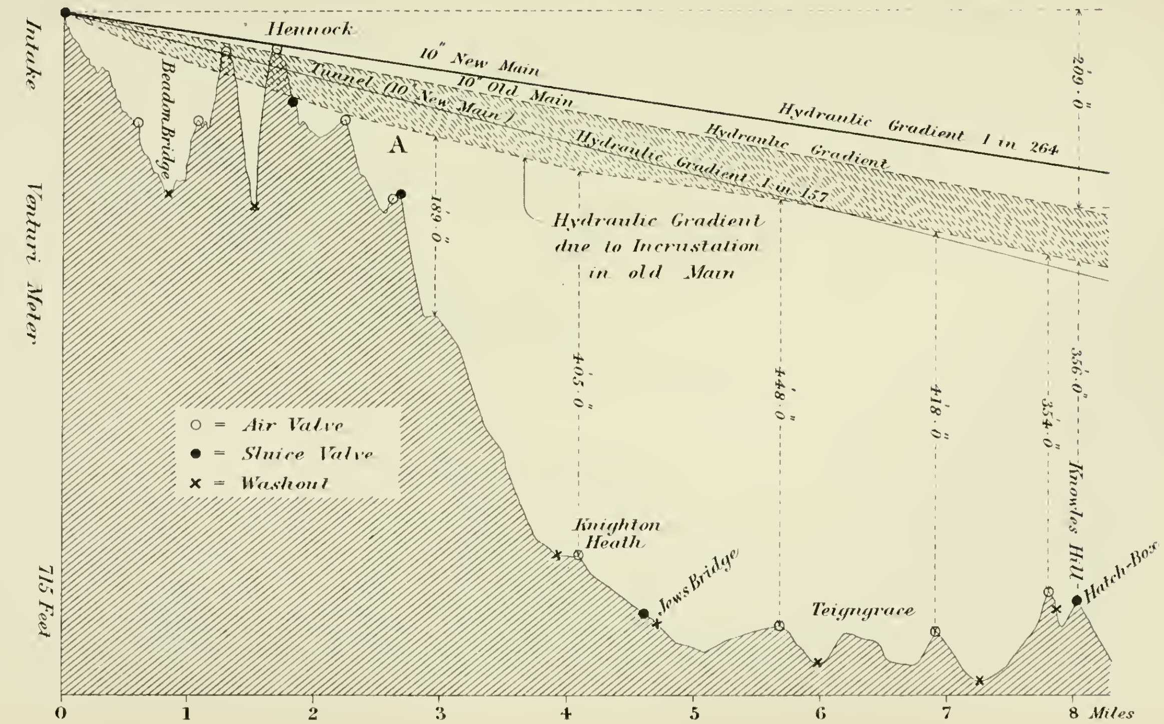


Fig. 3.
Froude.



INCRUSTATION OF PIPES AT TORQUAY.

Fig. 5. *Section of Pipe Line from Tottiford to Torquay.*



Continued on Plate 133.

Plate 132.

INCRUSTATION OF PIPES AT TORQUAY.

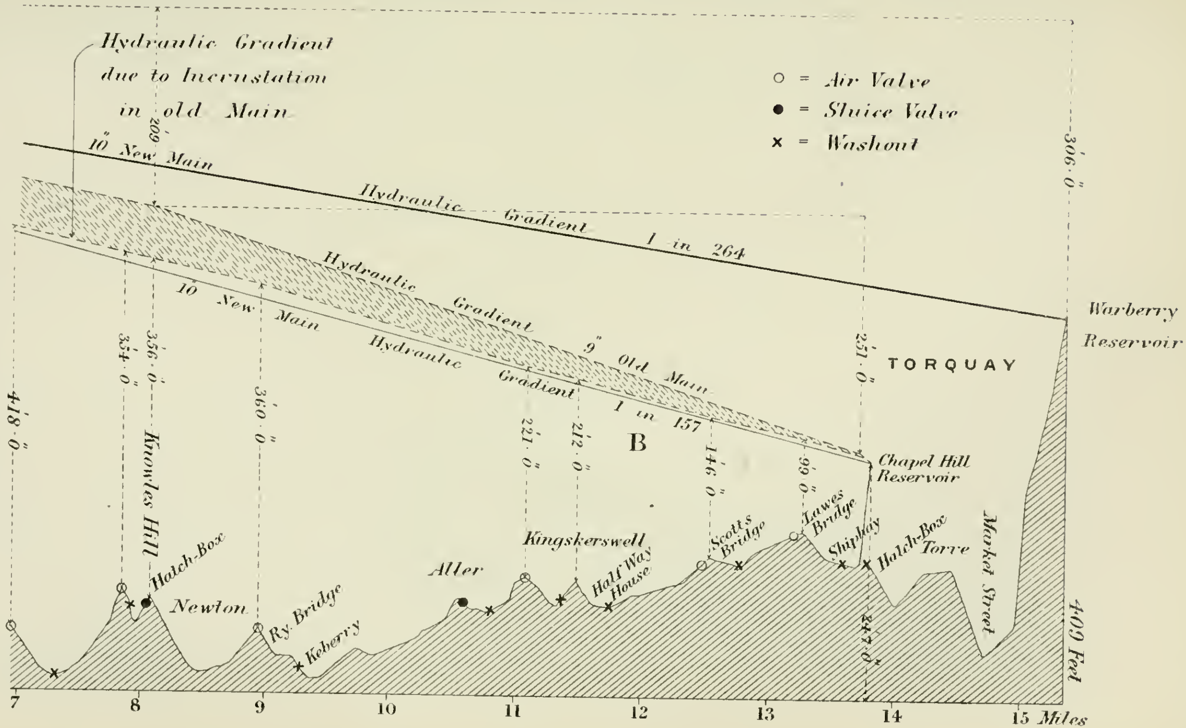


Fig: 6. Section of Pipe Line from Tottiford to Torquay.

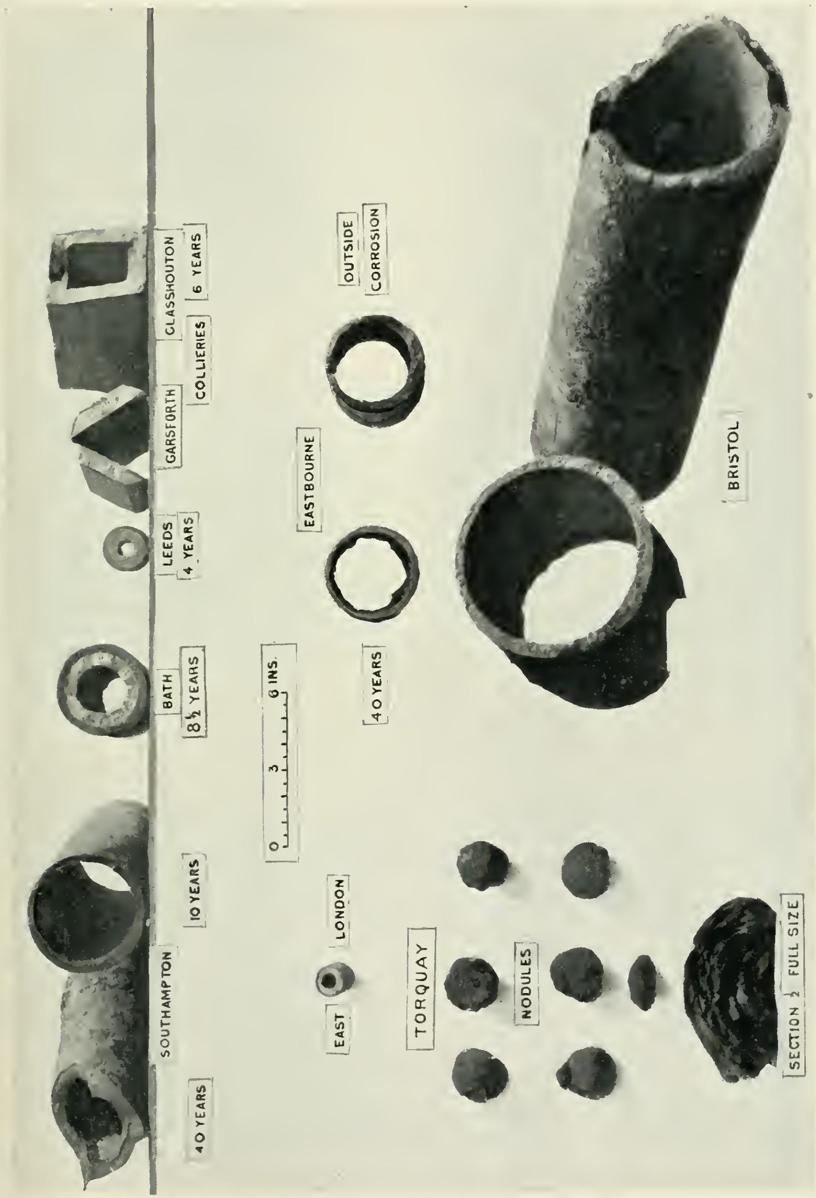
Continued from Plate 132.

Plate 133.

Fig. 7.

Specimens of Pipe Incrustation,

exhibited at the Meeting.



Outside- and Inside-Corrosion in still water,
Chapel Hill Service Reservoir.

Fig. 8. *Immersed 1881—1899.*

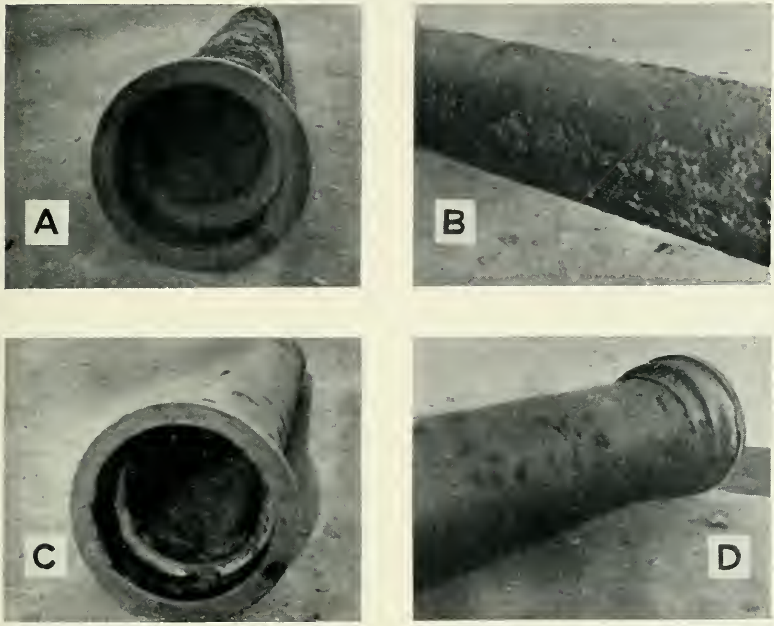


Fig. 9.
Small pipe, laid 1860. *Large pipe, laid 1882.*

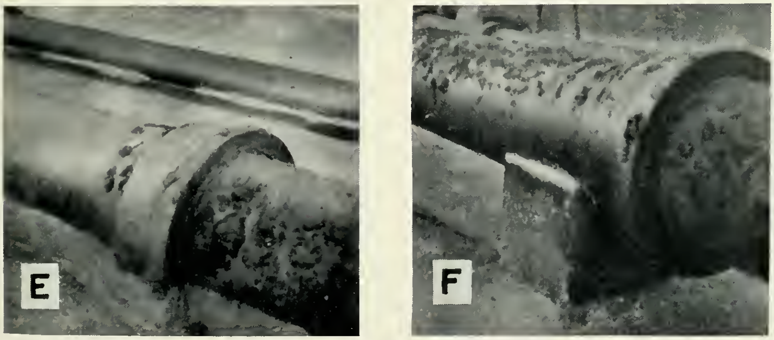
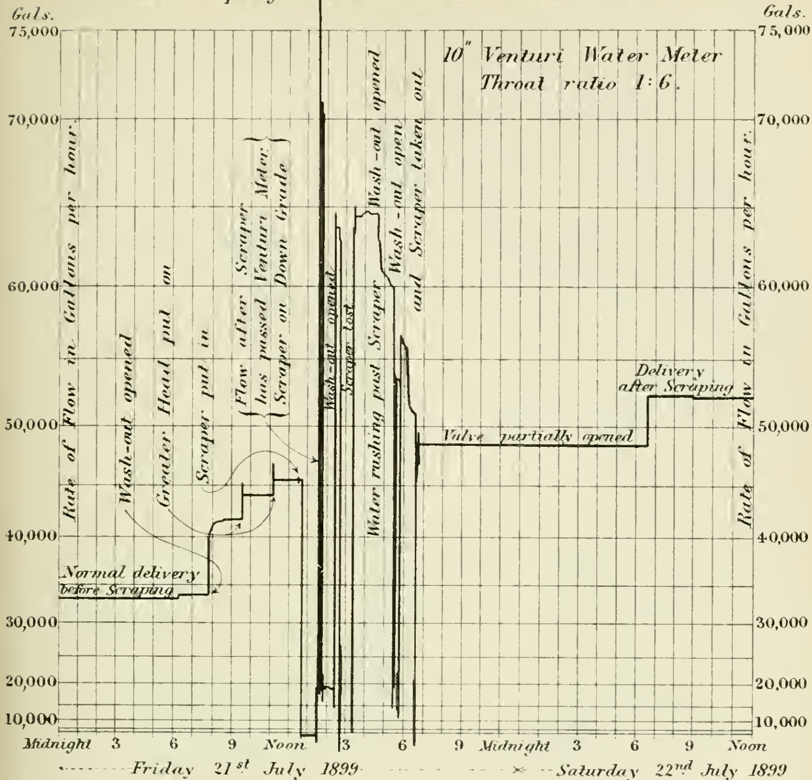
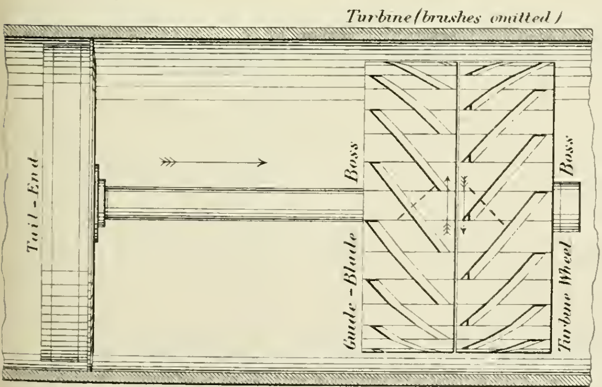


Fig. 10. *Diagram showing the quantity of Water used while Scraping the New Main. 8 Mile Section.*



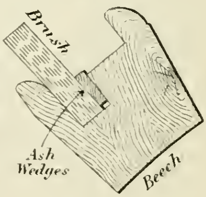
Deacon's Turbine Pipe-Brush.

Fig. 11. *General View.*



Scale 1/24th

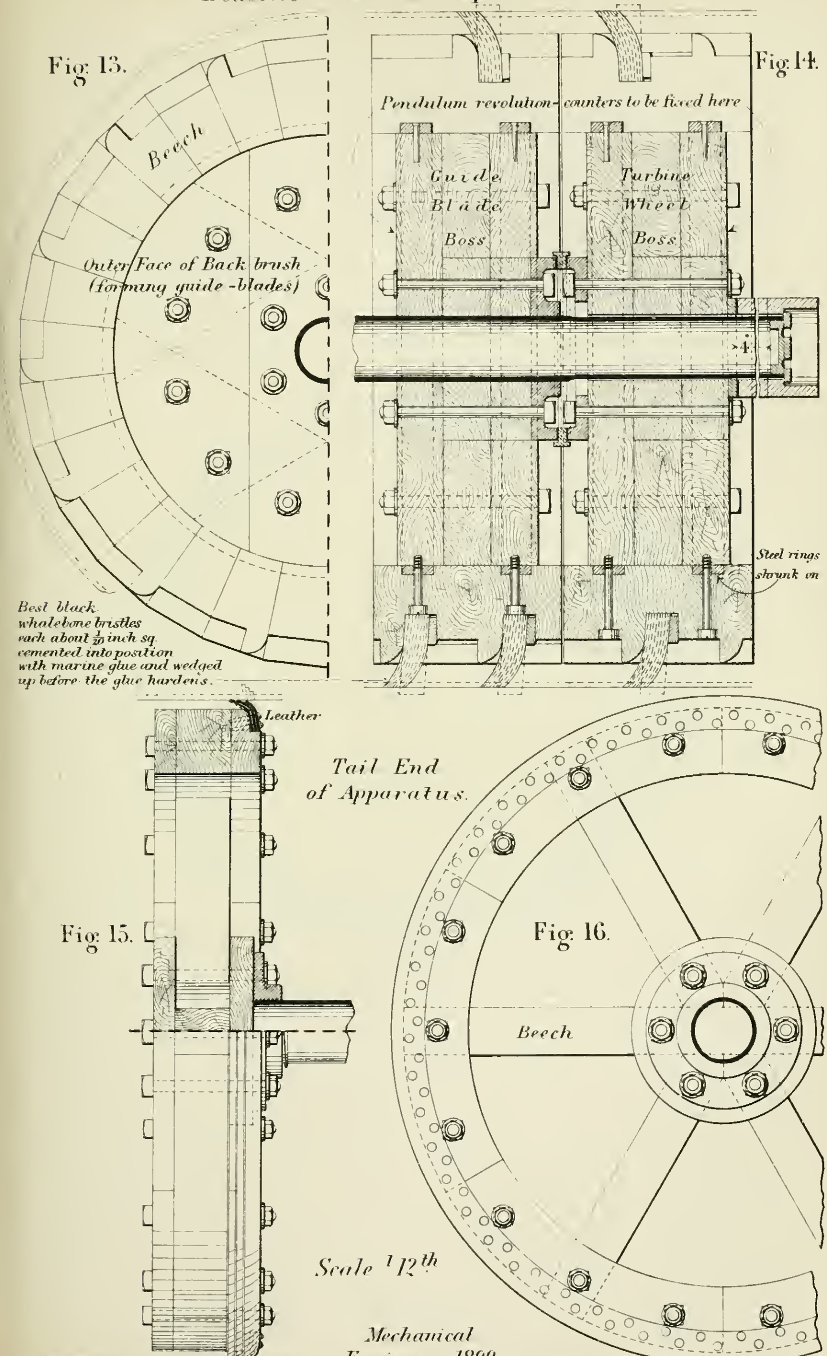
Fig. 12. *Section of Guide-Blade and Turbine Bosses.*



Scale 1/8th

INCRUSTATION OF PIPES AT TORQUAY. *Plate 137.*

Deacons Turbine Pipe-Brush.

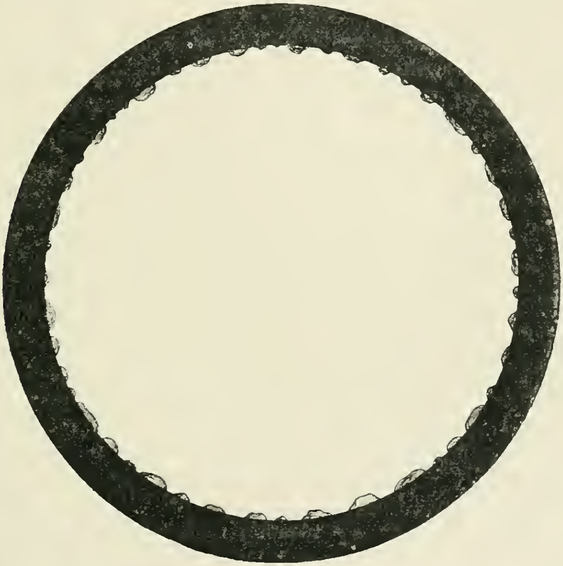


Mechanical Engineers 1899.

24 cubic inches of rust is formed per lineal foot of pipe, and as the length of the main is 24,352 yards we get 1,014 cubic feet of nodules. Now, as the nodule contains 49·03 per cent. by weight of iron, and a cubic foot of the incrustation weighs 93 pounds, the total loss of iron in the whole length of the main is no less than 21 tons per annum. This can be checked by taking the area of the inside of the main and multiplying it by $\frac{1}{4}$ inch, which is the thickness of the

Fig. 4.

Section of Pipe 10 *inches diameter, showing incrustation in one year.*



Scale $\frac{1}{4}$th.

iron lost by corrosion in forty-one years; this calculation gives 20·5 tons for one year, and compares very favourably with the first one, being only about $2\frac{1}{2}$ per cent. lower.

If before the scraping is commenced a pressure-gauge is fixed at different points in the pipe line, and the pressure plotted on a section, the condition of the pipe can be arrived at by comparing it with the theoretical hydraulic gradient of the pipe. The points on the section will show certain dips below the theoretical gradient owing

to the greater loss of head due to friction. If the dip is gradual it shows that the rusting is even throughout, but if the line rises and falls the rusting will be worse where the dip is largest and smallest where it is least. Special obstructions, such as a badly run joint or a heap of stones, would only show the dip at that point, and would recover itself immediately after passing it.

Plates 132 and 133 show the theoretical gradient and also that due to incrustation. It will be seen that the pipe is worst at A, Plate 132, whilst at B, Plate 133, it is in fairly good condition. The greater corrosion on the first section of the main is probably due to two causes.

1st. Because the water is impregnated with a greater percentage of gases on the first section, and thus increases the corrosive action;

2nd. Because the mains are washed out more at the end nearest the town, and some portion of the rust is washed away.

During the summer of 1896 it was found necessary to scrape the new 10-inch main* (which was coated with Dr. Angus Smith's composition), for the first time, and the deliveries into the Warberry reservoir before and after the scraping were 516 and 663 gallons per minute respectively, giving an increase of 28·5 per cent. For scraping purposes this main is divided into two lengths similar to the old main. It was laid in sections as required, having been commenced in 1877 and completed in 1891. The difference in head between the intake at Tottiford and the Warberry Service Reservoir is 306 feet and gives a hydraulic gradient of 1 in 264. During the scraping operations the scraper got through safely, but on arrival at the first hatch-box—8 miles from where it was inserted—it was found to be broken and badly strained. When however it is mentioned that 35 lbs. of joint lead, some yarn, and a bucketful of stones were in front of it, it is surprising that the scraper came through at all. The rear piston disc, two knives, one spiral and one longitudinal spring, were broken, and it cost £10 7*s.* to repair the damage before the second length of piping could be scraped.

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* Fig. 10, Plate 136, shows to one-third full size a diagram of the flow of water used while scraping in 1899 the 8-mile section of the new main.

The actual time taken to scrape the 14 miles of pipe was three hours for the first 8 miles and three hours for the second section of 6 miles, or an average of $2\frac{1}{3}$ miles per hour. There are seven scour-out valves on the 8-mile section and seven on the 6-mile. These are left open after the scraper has passed until the water becomes clean, and it is here that the time is lost, as in some cases this takes 20 minutes. A margin of time also has to be left between the opening of the next scour-out, and the one which has been reached, as the leading men cannot be seen on any part of the line. It is found that the greater the velocity of the water passing through the pipes the greater is the corrosion and incrustation so long as scouring action is avoided. In the Torquay mains the velocity of the water is rather high, being $3\frac{1}{2}$ feet per second in the 10-inch length of the old main and 4·32 feet per second in the 9-inch portion, while in the new main it is 4 feet per second. The analysis of a sample of rust taken from the Torquay main in May is appended, along with two other analyses from the water mains of Aberdeen.

TABLE 3.—*Analyses of Rust taken from the Torquay mains compared with that of Aberdeen.*

	Rust from 4-inch uncoated pipe at Aberdeen, 21 years in use.	Rust from 10-inch coated pipe at Aberdeen, 15 years in use.	Rust from 10-inch uncoated pipe at Torquay, 41 years in use. Rust only one year old.	
	Per cent.	Per cent.	Per cent.	
Volatile or combustible matter	16·62	18·05		
Sulphuric anhydride	0·60	1·08	1·44	
Phosphoric anhydride	trace	trace		
Magnetic oxide of iron	32·47	0·36		
Iron oxide	9·04	37·55	70·05	Fe_2O_3
Insoluble sandy matter	41·27	42·78		
Lime	trace	0·18	0·37	CaO
Moisture	..	..	13·60	
Combined water and organic matter	..	..	11·36	
Magnesia	..	..	trace	MgO
Silica	..	..	1·09	SiO_2
Combined Chlorine	..	..	trace	
Sulphuric Acid	..	..	1·44	SO_3
Carbonic Acid	..	..	2·12	CO_2

Two Analyses of Grey Pig Iron.

	Grey Iron.	Grey Iron.
Iron	93·30	94·56
Graphitic carbon	2·93	3·10
Combined carbon	0·61	0·04
Silicon	2·72	2·16
Sulphur	0·06	0·11
Phosphorus	0·03	0·63
Manganese	0·10	0·50
Copper	0·01	—
Arsenic	0·07	—

TABLE 4.—*Analyses of Torquay water before it enters the pipe at Tottiford, and when it reaches Torquay* (*distance* 14 *miles*). *See Plates* 132, 133.

	Parts per 100,000. Intake Tottiford.	Parts per 100,000. Tap, Town Hall, Torquay.
Appearance	clear	clear
Odour	none	none
Reaction	neutral	neutral
Colour of residue	dark brown	dark brown
Total solid matter	7·71	6·85
Chlorine	1·54	1·54
Equal to chloride of sodium	2·52	2·52
Nitrogen as nitrates and nitrites	0·208	0·064
Nitrogen as ammonia	none	none
Oxygen required to oxidise organic matter	0·088	0·061
Degree of hardness	2·54	1·78
Ditto after boiling ¼ of an hour	1·91	1·57
Organic carbon	0·144	0·144
Organic nitrogen	0·028	0·035
Silica	0·34	—
Ratio of brown to blue colour	40 : 20	40 : 20

Upon examination it will be seen that the solid matter, oxygen, hardness, and the silica, have been reduced to some extent in passing through the mains as follows:—

Solid matter	0·86 less.
Oxygen	0·027 ,,
Hardness	0·76 ,,
Silica	0·34 ,,

The percentage of iron in the rust is 49·03 per cent., leaving 50·97 per cent. for matter that has been deposited. This latter amount is composed of lime, organic matter, silica, carbonic acid, &c., so it is easy to trace where the different constituents were obtained for building up the nodules. A portion of the carbon, sulphur, and silicon is no doubt obtained from the cast-iron (see analyses) of the pipe, whilst the other portion is extracted from the solid matters carried in the water. The nodules of rust are made up of a series of layers, and these appear to increase in hardness the further they are from the centre. The centre portion of the nodule is generally made up of soft material, and when dry goes to a fine powder. The fact of there being a series of layers suggests that they are built up periodically like the rings in the harder kinds of timber. This may be due to the variations of heat, magnetism, greater acidity of water at one time than another, or some organic impurity in the water. The oxygen extracted from the water we know must pass through the outer layers before it reaches the iron of the pipe, and the outer layer is always less oxidised than the inner; whenever a nodule is cut off the pipe immediately after the water has been drawn off, this top layer will be found of a dark colour, whilst the inside will be the well-known brownish-red colour of iron rust. As soon, however, as the nodule has been taken away from the water and begins to dry, this dark layer changes by oxidation into the brownish-red colour of the interior.

The chemical action in the formation of rust is as follows:—The iron is first attacked by the carbonic acid and water, and this forms ferrous carbonate thus:—

$$(1)\ Fe_2 + 2CO_2 + 2H_2O = 2FeCO_3 + 2H_2.$$

The ferrous carbonate is then dissolved by the excess of carbonic acid in the same manner, as the $CaCo_3$ is held in solution by chalk water. Ferrous carbonate, being a very unstable compound, is quickly oxidised by the oxygen in the water, and forms ferric oxide (Fe_2O_3) and carbonic acid gas thus:—

$$(2)\ 2FeCO_3 + O = Fe_2O_3 + 2CO_2.$$

It will therefore be seen that a similar amount of carbonic-acid gas is given off in No. 2 as is used in No. 1; so it follows that a small quantity of carbonic acid suffices to keep up the reaction. Ferric

oxide is not magnetic, but ferrous carbonate is, and no doubt this magnetism plays a very important part in the rusting of water-pipes.

The incrustation or deposit varies considerably in different districts. At Southampton, where the water is derived from wells sunk in the chalk, the coating is of pure calcium carbonate, which is very pretty to look at, and forms a desirable interior surface from one point of view, if not from the other of reduction of pipe area. The chemical analyses of the water is appended, and Mr. William

TABLE 5.—*Analyses of Otterbourne Water, Southampton Water Works.*

General Analysis.	Well Water. Parts in 100,000.	Softened Water. Parts in 100,000.
Total solid matters	31·69	14·07
Organic carbon	0·024	0·021
" nitrogen	0·012	0·013
Ammonia	0·005	0·004
Nitrogen, as nitrates and nitrites	0·365	0·381
Total combined nitrogen	0·381	0·397
Chlorine	1·6	1·6
Mineral Analysis.		
Silica (SiO_2)	1·02	0·94
Oxide of iron and alumina $\left\{\begin{matrix} Fe_2\,O_3 \\ Al_2\,O_3 \end{matrix}\right\}$	0·14	0·11
Lime (CaO)	14·53	4·42
Magnesia (MgO)	0·25	0·28
Soda (Na_2O)	1·21	1·12
Sulphuric acid (SO_3)	0·39	0·45
Nitric acid (N_2O_5)	1·41	1·47
Chlorine (Cl)	1·60	1·60
Carbonic acid (CO_2) from carbonates of lime and magnesia	10·64	2·64
	31·19	13·03
Less oxygen—equivalent of chlorine	0·36	0·36
Total solid residue	30·83	12·67
Carbonate of lime ($CaCO_3$)	23·93	5·67
" magnesia ($MgCO_3$)	0·21	0·29
	Degrees.	Degrees.
Hardness { Temporary	16·10	3·92
Hardness { Permanent	1·89	2·13
Total	17·99	6·02

Matthews, the Borough Water Engineer, had kindly supplied pieces of pipe for inspection, showing the deposit and incrustation after being in use for forty and ten years, Plate 134.

At Bath the water (which is from an upland surface) is obtained from the Oolite and Lias formations, and the deposit is composed of $CaCO_3$, $CaSO_4$, and Fe_2O_3. Mr. Charles Gilby, the Water Engineer, has been good enough to supply the following analyses of the water, and also of the deposit in the mains :—

TABLE 6.

	Grains per Imperial gallon.	or —	
Lime	21·14	Carbonate of lime . .	32·15
Magnesia	0·80	Carbonate of magnesia .	1 68
Soda	0·34	Sulphate of lime . .	12·30
Chlorides of sodium and potassium . . .	5·50	Sulphate of soda . .	0·78
Oxide of iron, silica, &c. .	0·70	Chlorides of sodium and potassium . . .	5·50
Sulphuric acid . . .	7·68	Oxide of iron, silica, &c. .	0·70
Carbonic acid . . .	16·95	Organic matter . .	0·79
Organic matter, &c. . .	0·79		
Total solid matter . .	53·90		53·90

Hardness of water before boiling . . .	35·1
Hardness of water after boiling . . .	14·6

Analysis of Deposit in Iron Water-Pipes.

	Bottom of pipe.	Top of pipe.
Carbonate of lime . . .	97·58	98·55
Sulphate of lime . .	1·32	0·54
Oxide of iron, &c. . .	1·10	0·91
	100·00	100·00

Two inches in length of 6-inch pipe contained 26·786 grains, or 23 lbs. per foot, or 69 lbs. per yard = 5·42 tons per mile.

A 3-inch sample, showing the deposit, after being in use for $8\frac{1}{2}$ years, was submitted for inspection, and is reproduced on Plate 134.

At Brighton, with water from the wells in the Upper Chalk, there is very little deposit or rust, while at Leicester, where it is obtained from an upland gathering ground of Slate Rocks and Red Marls, they are compelled to scrape the mains.

At Nelson and Burnley the water is from the Millstone Grits, and both are upland supplies; in these cases the mains require scraping, and in the first case an accumulation of 13 years' rust reduced the delivery of a trunk main from 1,120,000 to 811,000 gallons per day.

At Stroud, with well water from the Mitford Sands and Blue Lias, they are troubled with a deposit of lime.

Where well waters are derived from the old red sandstone formation they are not as a rule troubled much with either incrustation or deposit, but water from the greensand causes rust in some cases.

Speaking generally it may be laid down with a fair approximation to the truth that well waters have not as great an action on pipes as those from upland gathering grounds, but where the water is soft the corrosive action will be greater. Filtered water has also a less corrosive power than unfiltered water.

The liability of cast iron, wrought iron, and steel to oxidise is as follows:—

Cast iron	100
Wrought iron	129
Steel	133

Engineers who have to deal with soft upland water supplies should take these figures into careful consideration when designing their pipe lines.

Whatever protective covering is applied to pipes, soft waters will cause rusting within a few years of being laid. At Torquay six years is the outside limit when this commences, so every precaution is taken to see that the pipes are well coated.

The alkalies, alkaline carbonates, and ammonia have a slight dissolvent action on Dr. Angus Smith's composition, and the Torquay water is slightly alkaline at times, whilst at others it is slightly of an acid character, probably due to peat. At the same

time there is always a small amount of free ammonia present, and probably that is the reason of coated pipes rusting within such a comparatively short period.

In some pipe foundries it is to be regretted that those in charge do not study this subject of rusting sufficiently, and therefore fall into the error of supposing that a little preliminary rusting before the dipping takes place does not matter. For water from granite districts especially the question of rusting is paramount, and water engineers should insist upon the pipes being free from scale and rust before dipping.

The method usually adopted in this country is to heat the pipes in an open cylindrical stove of brickwork at the bottom of which is a fire, and when the pipes have attained a heat of about 600° Fahr. they are dipped in composition near boiling point. The pipes are left in this composition until they have acquired the temperature of the liquid, and are then taken out and allowed to cool whilst hanging. Any portion of the coating which is damaged while the pipes are being handled should be painted with a natural asphalte dissolved in bisulphate of carbon.

The following process has been recommended for steel pipes. During rolling it is found that the surface of the steel is changed into a magnetic oxide (black oxide) which resists corrosion but soon scales off. This scale should be removed by placing the pipes in a sulphuric acid bath, followed by one of lime water immediately before the plates are riveted up, and then dipped in nearly boiling asphaltic composition. The composition should be natural asphalte containing a large proportion of bitumen, with just sufficient creosote oil added to make what is necessary to produce when cold a smooth plastic and strongly adhesive varnish.

Much has been done to get a satisfactory coating to pipes, but there is still considerable room for improvement, and it is hardly necessary to point out that a fortune awaits the man who can invent something that will withstand the action of soft waters.

The author cannot conclude this Paper without expressing his thanks to those Water Engineers who have been kind enough to give

him the benefit of their experience and also for kindly forwarding the samples exhibited, Plate 134. His thanks are also due to Mr. John Taylor, F.L.S., F.C.S., of Torquay, for some of the suggestions in the chemical part of the Paper.*

Discussion.

Mr. Ingham said that several samples of pipes had been sent to the Institution, showing the corrosion in different districts; two from Mr. H. W. Pearson, the water engineer of Bristol, three from Mr. A. Tannett Walker, Vice-President, and two from Mr. J. T. Rodda, of Eastbourne; these are shown on the photograph, Plate 134. Other samples were also on view, including pieces of iron pipes from the Southampton and Bath Water Works, a piece of lead pipe from the East London Water Works, a piece of incrustation from a pipe at the Garsforth Colliery near Leeds, nodules showing forty years' rusting at Torquay, Plate 134, and three different kinds of scrapers, Plate 131. There were some points in the Paper upon which he was not very clear, and upon which he would like a little more light thrown during the discussion. He noticed there were several members present who, with Mr. Froude, had gone into the question of scraping at Torquay; amongst them were Sir Frederick Bramwell and Mr. H. M. Brunel, and he hoped that those gentlemen would give the members the benefit of their long experience. Before the Discussion commenced he would explain the action of the scrapers, Plate 131. The scraper was put into the pipe with the discs in the rear. There were two pairs of knives placed diametrically opposite one another, one pair being placed about 4½ inches behind the other. When the inclined portion of the knife came into contact with an obstruction, it stretched the spring, and forced the knife back, at the same time turning

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* For further Paper on the Scraper, with illustrations, see Proceedings 1873, page 216.

the scraper bodily round, thus allowing it to pass the obstruction. The pressure outwards was given by another spring underneath each of the helical ones. The pressure of the water acting on the two discs sent the scraper forward. The front metal piston tended to keep the leathers from being worn away too quickly, by taking away certain portions of the rust which the knives had not taken off. Fig. 3, Plate 131, represented the scraper they used at present, and he thought the design was due to Mr. Froude alone. Fig. 1 was Mr. Appold's scraper, and he believed he was right in saying that Mr. Appold never saw it at work, but died on his way to Torquay. With regard to Fig. 2, he thought Mr. Box, who was engineer to Messrs. Easton and Amos, and Mr. Froude designed it. He had no definite information on that, but perhaps Sir Frederick Bramwell or Mr. Brunel might be able to explain matters fully. The samples of reddish nodules, Plate 134, had come off the Torquay pipes. These nodules represented samples of rust accumulated in forty years on an uncoated pipe, and caused a reduction in the discharge of 42 per cent. Of course a year's rusting was much less than that, the nodules being about half-an-inch in diameter and $\frac{3}{16}$ inch high. Plate 135, A, B, C, and D, showed two pipes which were placed in the Chapel Hill service reservoir about the year 1881 to test the effect of still water on the coating. It would be noticed that the pipe A and B was much more corroded than the pipe C and D on the outside, whilst C was worse than A on the inside. This might be due to the pipes not being properly cleaned after they had left the mould. E and F showed two pipes laid in the same reservoir, the smaller being laid about 1860, and the larger about 1882. It would be noticed that the smaller pipe was in a much better condition than the large one, although pipes in the same line showed very different corrosive results, as was seen on photo E.

The President said that before proceeding to the discussion he would ask the Members to authorise him to present on their behalf their best thanks to Mr. Ingham for his very interesting Paper. They were the more indebted to him because their proceedings at Plymouth, at which that Paper was intended to be included,

(The President.)

extended to such a length that, although Mr. Ingham was ready to proceed with his Paper, and had the scrapers there, they were compelled to ask him to postpone it. Of course in coming to London from Torquay he had laid them under a still greater obligation. He would ask Mr. Brunel, who had an intimate personal acquaintance with the water works at Torquay, to open the discussion.

Mr. H. M. Brunel said that he had not had charge of the actual scraping, but had seen it in 1866 when it was being carried on under the advice of Mr. William Froude. He himself (in 1876) advised the Local Board with regard to their new main, the 10-inch main described in the Paper, from Tottiford to Torquay, both with regard to the size of the pipe, the sections in which it should be laid, and the order in which these sections should be carried out. In the new main, provision was made for scraping, if it became necessary. Hatch-boxes were put in at the end of each section, and there were cross-over pipes between the two mains, so that the water might be passed in any desired direction. The part of the main which was actually laid under his supervision was the small piece at the beginning, about two miles from Tottiford to Hennock, and the last piece from Aller to Torquay, a length of about four miles. The reason for laying the part between Tottiford and Hennock first was that there should be no tendency for an air-lock to occur near Hennock. The old main went through a tunnel at the summit, and the new main was carried round the contour of the hill. The subsequent portions of the main were laid as recommended by him, but under the supervision of Mr. Weeks, the water engineer. With regard to the history of the matter, he would like to refer to opinions expressed at the time. Mr. William Froude had been called in to advise the Local Board, and his first step was to try and ascertain the facts. By two very good pressure-gauges he took levels and pressures all along the main, and satisfied himself and the Local Board that the defect was a uniform one, and not due to incidental obstructions. Thereupon Mr. Appold made the suggestion of the scraper, which was tried, and proved very successful on a short length of pipe at Jews Bridge. The results indicated an immense

advantage in the flow of the water, and the authorities gave instructions for the work to be continued. It can scarcely be said that any one of the scrapers can be named after any one man. Mr. William Froude and Mr. Thomas Box worked these designs out at Messrs. Easton and Amos's works at the Grove, Southwark. The curiously-shaped curly scraper, Fig. 2, Plate 131, was made with the object of getting more range, in a direction radial to the pipe, by putting the pin on which the scraper-arm turned at the side of the machine farthest from the actual scraper. In 1869 Mr. R. Edmund Froude, who had studied the matter while his father was carrying on the work, wrote :* "The defect was attributed to internal oxidation ; but as this, though forming a rough carbuncular surface, did not much exceed $\frac{1}{8}$ inch in average thickness, the obstruction would have been insignificant, according to the commonly received view that the water detained in the roughnesses would furnish a smooth surface for the internal column to glide through ; and it followed that either the received view needed some correction, or that local obstructions must have been established by accumulations of sediment or otherwise in the many deep depressions of ground-surface traversed by the main." Mr. William Froude had, by the pressure-gauge observations, proved that there were no reasons to suppose the presence of any local obstructions. The Paper immediately following Mr. R. E. Froude's Paper in the Exeter Report is one by Mr. William Froude, and bears on the subject of the flow in pipes, and is of much interest. In 1873 Mr. Little, the engineer of the Torquay Local Board, read a Paper † before this Institution, in the preparation of which he was assisted by Mr. Weeks. During the discussion Mr. Froude referred ‡ to the old opinion : "One point of interest was the original determination of the fact that the obstruction to the flow of the water was due to the incrustation of oxide of iron within the pipes, although the diminution of the diameter was certainly trivial. The old opinion of hydraulic engineers had been

* British Association Report, Exeter Meeting, 1869, page 210.

† Proceedings, Penzance Meeting, 1873, page 216.

‡ *Ibid.*, page 224.

(Mr. H. M. Brunel.)
that the mere roughness of the pipe would not cause such an amount of obstruction as was experienced." (It would be remembered that this diminished the flow by 50 per cent. The flow was one-half what it ought to be in the pipe.) "It was held that part of the water would become entangled in the interstices of the rough surface, which would thus be smoothed over, and the rest of the water would thereby be slipping along upon water instead of upon the rough surface of the pipe." That Paper of Mr. Little's and the discussion following it were well worth looking at.

The PRESIDENT understood that Mr. Brunel had actually seen Mr. Froude's scraper at work at the start.

Mr. BRUNEL said he had not seen it, but that he had heard it. He thought Sir Frederick Bramwell would be able to give a more graphic description. He, Mr. Brunel, had run along the pipe line with many members of the Local Board. It was very interesting to see a lot of respectable gentlemen running along a turnpike road, stopping occasionally with their ears to their umbrellas and walking-sticks held to the ground, with two or three navvies lying flat on the ground, listening for the passing of the machine. That was in 1866 or 1867.

Mr. GEORGE F. DEACON had listened with great pleasure to the Paper, as it dealt with a subject with which he had been concerned for very many years. On page 490 it was said: "The greater corrosion on the first section of the main is probably due to two causes, first, because the water is impregnated with a greater percentage of gases on the first section, and thus increases the corrosive action." He might say at once that that statement was not borne out by the latest investigations. It was not mainly the gases in the water that caused the incrustations and other obstructions, but to a much larger extent the acidity, to which many upland waters were liable. It was suggested in another part of the Paper that alkalinity dissolved the asphaltic coating. That might be the tendency, but, whether it was so or not, alkaline water

took a very much longer time than acid water to cause corrosion in coated iron pipes. Again, it was not the softness of the water that did the harm; but as it so happened that soft water was more commonly acid than hard water, the effect was often attributed to softness.

He now came to the very important point of the nodular oxide formation in cast-iron pipes. It not only took place in cast-iron pipes, but also in steel and in wrought-iron pipes. From some cause or other the forms taken by these oxide nodules were entirely different from the forms of ordinary iron-rust. To begin with, it was an undoubted fact that such nodules grew upon the surface of the asphalte, and, when a nodule was carefully removed without disturbance of the asphalte, he had always found some defect in the asphalte, perhaps only a minute puncture near the centre of the nodule. The nodule grew through that defect or puncture, and spread over the surface of the asphalte in concentric layers. The iron below and around the puncture became spongy and could often be cut with a knife, the decomposed portion having a somewhat conical form, with the base of the cone touching the inside of the asphalte coating, just as the base of the much larger oxide nodule touched the outside. The two were nearly concentric, and the defect in the coating was near their common centre. For a long time the asphalte coating remained quite perfect, excepting at the small defect between the decomposed iron below and the nodule above. In the process of years, however, some of the asphalte was taken up bodily by the nodule, and became mixed with it, and in process of time—though it took a very long time if the coating was good—it was found that the whole of the coating disappeared, first, around the centre of the nodule, and gradually towards the sides. Prevention was better than cure, and he was therefore led to consider what precautions ought to be taken to avoid the little defects in the coating, which appeared to be the beginning of the disease. As it seemed to him, some if not all of the defects were probably initial: they might be due to particles of grit or to tiny air-bubbles at which the asphalte film, while cooling, would become thinner, and perhaps break; but whatever the cause, the single

(Mr. George F. Deacon.)
coating did not seem to be quite continuous. In his own practice he had endeavoured to overcome that difficulty by applying two coats, two dippings, allowing the first to cool to a sufficient extent for the asphalte to set before re-dipping. He also believed that, in the first instance, it was an enormous advantage to dip a pipe cold, and, both in the first and second instances, to allow it to be heated up to the boiling point of the asphalte by means of the bath alone. Dr. Angus Smith's process was simply the use of coal tar for the purpose they had been discussing. Pitch and creosote oil were more commonly used now, and in America a natural asphalte, in which almost any desired percentage of bitumen could be obtained. He had tried the latter in this country. He confessed that his mind was still open to conviction as to the best ingredients for the dipping pan, but as to the process already stated he felt no doubt; and he would add that all arrangements for heating either the pipes or the asphalte directly by furnaces were bad. The best method by far had been used in America. It was simply a steam coil inside the asphalte bath, which could be regulated to any degree of temperature by changing the pressure. With regard to the obstruction in iron pipes, rust nodules were not the only sinners. There was a deposit, well known in pipes conveying mountain water, which had somewhat the appearance of coffee grounds, and was commonly known as peaty deposit. This had very much more to answer for than was generally supposed. Until within the last few years he had himself believed it to be peat. That it was not peat could be easily seen by anybody who took the trouble to put it into a bottle with its own water, and allow it to stand. It settled rapidly to the bottom, and left the water without a stain, which peat would not do; moreover, it was found in pipes from reservoirs upon the drainage areas of which there was no peat. [Mr. Deacon here handed to the President a little bottle containing the black-brown substance.] This was a heavy deposit, containing generally but little peat or other dead organic matter. It had been examined by Dr. Campbell Brown and Professor Robert Boyce, the eminent chemists and bacteriologists of University College, Liverpool, and had been shown to consist mainly of oxides of iron and manganese; the iron, dark red, the manganese,

black, with some mechanically included clay. Like most engineers concerned with upland waters, he had long known this material, and had called it peaty deposit; but about two years ago, having been called upon to investigate the causes which had led to the retardation of the flow in the upper part of the main from Lake Vyrnwy to Liverpool, he discovered his mistake. The portion of that main between the lake—or the tunnel leading from the lake, and the tunnel leading to the Oswestry filter beds—was 13 miles long, and it had diminished in carrying power from between 16 and 17 million gallons a day to between 12 and 13 million gallons a day in a comparatively few years. He had investigated the matter thoroughly, inside and outside, in every possible way. This 13 miles of main was so proportioned, and laid at such a gradient that, other things being the same, it would discharge a little more water than the rest of the aqueduct from the Oswestry filter beds to the service reservoir at Prescot. Physically it only seemed to differ from the lower portion in two respects, namely, it contained unfiltered water, and passed over a much more hilly country. On the interior there were some rust nodules, but, although the main had been laid for fifteen or sixteen years, they were not sufficiently developed to account for the increased resistance. The scour valves were used, and the dark deposit having appeared as usual, it was analysed, with the result just stated. When freshly obtained it would roll about under water in a basin, almost like minute marbles, and it occurred to him that a material of that kind lying in all the inverted syphons, of which there were about twenty-six in the 13 miles, would rush rapidly down the twenty-six downhill portions, and, impelled by the water to ascend the corresponding uphill portions, would do so less rapidly than the water and would accumulate in those portions, increase the density of the fluid, and, rising among the eddies and constantly falling back, it would in great measure fail to reach the summit. One could conceive the aggregate effect of these twenty-six independent brakes upon the single stream: it seemed to him quite sufficient to account for the loss of head which had occurred. He had stated generally the nature of the material found loose in the pipes. The same material, in a more coherent or slimy condition,

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coated the interior of the pipes, but so smoothly that very little increase of resistance could be attributed to that cause. The origin and exact nature of the material was receiving very thorough investigation by Dr. Campbell Brown, who had examined the deposit and the water containing it from many different sources. The final conclusions had not yet been reached, but there could be no doubt that bacteria were very largely responsible for its production, and that the iron and manganese were supplied largely—if not wholly—by the water, and not by the iron pipes. This led one to inquire whether bacteria were the cause of the differences between the rust nodule in water pipes and other forms of rust. It would probably transpire that they were the cause. The whole inquiry was a most difficult and interesting one, and we might hope before long to hear much more about it from Dr. Campbell Brown.

He had had occasion to scrape many mains, but had always found that, once begun, it was necessary to repeat the process every year or two. The growth of oxide nodules after scraping was much more rapid than when they were left to themselves. At the same time there were of course very many instances in which scraping was justified by the circumstances.

About the year 1872 he designed and had constructed a scraper for use in the 44-inch main from Rivington to Liverpool. In order to equalise the radial pressure, this apparatus was constructed on a floating steel drum. The main, laid about the year 1854, was said to have discharged when first used 17 or 18 million gallons a day, and it was not coated with any preservative composition. It seemed probable that not very many years later the discharge was reduced to about 12 million gallons a day, a condition which had not since then materially changed. From this and other cases there was reason to believe that when once the interior had, as in this case, become completely covered with rust nodules, those nodules in a few years attained their full size, produced their maximum resistance to the flow of water, and preserved the iron beneath them entirely, or almost entirely, from further decomposition. His personal experience of the Rivington main had extended over twenty-eight years, and from his knowledge of what had occurred

before that time, he could say that no important change had taken place during the last thirty or thirty-five years. Under these circumstances he thought wiser counsels had prevailed, and the apparatus constructed for scraping the main had never been put into use.

The Vyrnwy pipes had been coated with asphalte as well as was possible by a single dipping, and he was reluctant to do anything in the way of scraping, which would certainly damage the coating. Some good had been done by flushing, but this alone was not sufficient, and he decided to assist the process by brushing. The main in this part of the aqueduct, 13 miles in length, was 42 inches diameter, and the apparatus which was employed for brushing it out might be described as a parallel-flow turbine pipe-brush. The guide blades were arranged helically around a solid timber boss, and filled the space between that boss and the pipe. The turbine wheel was an exactly similar boss, with vanes similarly filling the space, but arranged in the opposite direction to the guide-blades. Both guide-blades and vanes consisted of whalebone bristles, and the bosses carrying both were mounted on a hollow steel shaft having at its other end a wheel-shaped boss which fulfilled two functions, the first being to maintain the parallelism of the turbine, the second to resist the longitudinal movement of the turbine and to ensure the velocity of flow in the main being very much greater than that of the apparatus, without which excess the bristles would give merely a straight sweep, and would immediately become choked by the accumulations which they themselves produced. Fig. 11, Plate 136, is an elevation of the apparatus in which the guide-blade and turbine wheel-bosses are shown with the recesses for the bristles, but without the bristles. The bristles are shown in Figs. 12 and 14, and the tailpiece in Figs. 15 and 16. This is simply a strong timber wheel carrying three rings of leather ; thus the apparatus only touched the pipe at its forward end through the medium of the bristles, and at its rear end through the medium of leather. The machine gave excellent results from the first, but it required a little time to ascertain the best velocities and other conditions. It was ultimately found that all that was desired could be done with the water flowing at the rate of only a mile an hour, while the machine moved at only

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one-third of a mile an hour, but owing to the contracted spaces between the guide-blades and vanes, the water moved through these at 10 miles an hour, or nearly 15 feet a second. On first thoughts it might be supposed that the mean velocity of a mile an hour would be quite insufficient to clear the front of the machine of the accumulations brushed up by the bristles and by the high velocity at the sides of the pipe, but this was not so; although the mean velocity was slow, the eddies proved to be abundantly sufficient to keep the water in a state of considerable agitation to the next sluice cock. These sluice cocks were 12 inches diameter, and only required to be partly opened. After the starting of the apparatus, say on a length of two miles, discoloured water containing a considerable proportion of the loose deposit soon appeared at the sluice, and this proportion continued much the same until shortly before the apparatus reached the sluice cock, when it rapidly increased, showing, as might be expected, that, though the pipe was quite free just in advance of the machine, there was a huge accumulation of loosened matter a little further on, analogous to the inevitable sandbank found a mile or two below the weir at the tidal head of a river, although deep water always occurred nearer to the weir.

It is important to note that the apparatus when first applied was perfectly silent and could not therefore be followed on the surface. If it had permanently stuck at any point its position would not have been known, and much trouble would have arisen, but happily this contingency did not arise, and before the work was half completed its position was continuously known by the application of a gong—on the principle of the spring stamp-hammer—constructed by the village blacksmith and joiner, and carried by the machine. The gong was driven by helical vanes of hard wood, arranged after the manner of windmill sails, and nearly the full diameter of the pipe, placed in front of the turbine wheel, where the velocity of the issuing water was high. These vanes, revolving on a projection of the shaft, carried a revolving tappet and lifted a considerable weight held against the shaft by a strong steel spring. On being released the weight struck the shaft a blow which was sufficiently heard at the surface. Thus, while the turbine-brush moved at its

ordinary speed, the frequency of the blows was moderate, and when retarded or temporarily stopped by increased resistance, the frequency was obviously increased. Towards the end of the work a portable telephone was also used, and such control was thus obtained that directly more pressure was required it was readily applied.

The principal difficulty at first met with was to prevent the forward motion of the apparatus from becoming too quick, so that sufficient rotary motion was not produced. The leathers on the tail-piece began to wear, and as they rubbed upon the already cleaned surface they ceased to hold back the apparatus sufficiently to give the necessary velocity past the blades. In consequence of this the tailpiece was dispensed with and the machine was turned end for end, the forward end being provided with strong steel springs carrying bosses of timber in two rings, so arranged as to break joint and bear against the whole circumference of the pipe. This arrangement proved effective. The result of brushing out in this manner, both before and after the alteration just referred to, was as perfect as it could be, the deposited material, whether adhering to the surface or loose in the inverts of the pipes, was entirely removed without damage to the asphalte coating, and on the completion of the work the discharge was increased from 12 or 13 million gallons a day, to between 16 and 17 million gallons a day, being substantially the same as the discharge of the main carrying the filtered water onwards between Oswestry and Prescot. The effect of the deposit had thus been successfully but temporarily removed while the cause remained untouched; and it is not surprising therefore that deposits are again accumulating. From this experience, and from other cases which he himself had observed, it was perfectly clear that filter beds ought, whenever possible, to be not very far from the source of supply. It appeared that filtration, whether by neutralising the water or otherwise, almost entirely prevented the formation of the deposit to which he had referred, and he was disposed to think that if pipes for use with such waters were double coated in the best known manner, and if the water were filtered before entering them, a discharging power would be maintained such as new and clean pipes were known to realise,

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and which would far more than compensate for any additional expenditure thereby incurred. It had been suggested that pipe manufacturers would not put down plant for coating pipes in a manner to which they were not accustomed. The matter, however, was entirely in the hands of the engineer, and if engineers specified what was necessary to produce a good result, they would certainly find manufacturers ready to carry out the work.

Mr. Charles Hawksley said that, although he had naturally known the process of scraping for a considerable number of years, and had been familiar with its successful application, he had never had personal experience of it. He therefore was unable to add much to what had already been said with regard to the use of the scraper. There were, however, one or two points to which he might make reference. In one portion of the Paper, page 487, the effect of scraping was gathered from a comparison of the actual delivery of the pipe after scraping with the theoretical delivery. That could hardly be considered a very satisfactory method, and he much preferred the results in Table 1, where the actual delivery before scraping was compared with the actual delivery after scraping. The deliveries after scraping in different years were also compared, but whether the increased delivery as time went on was, as suggested, entirely due to the enlargement of the pipe by the rusting away of a portion of the metal itself, or whether it was due to the earlier applications of the scraper not having completely effected the cleansing of the surface of the interior of the pipe, required careful consideration, before a loss of thickness in the metal pipe could be deduced from the results. The author spoke of the coating of the pipes, and said they were usually heated before being put into the pit or the tank containing the coating material. Unfortunately he was afraid that previous heating was very often neglected. The pipes were put cold into the coating material, and were not allowed to remain there for a sufficient length of time to enable them to attain to the proper heat before they were withdrawn. In that case the material was not properly applied. In order to prevent as far as possible the oxidation of the pipes in the process of proving, his

father had, in some instances, had the pipes tested with oil instead of water. That was done in the case of the pipes for the Vyrnwy main to which Mr. Deacon had referred.

Mr. Edward M. Eaton said that he had had a rather extended practical experience on the subject. He happened to have been the engineer in charge of the distribution of water in Sheffield for thirty years past. The Sheffield water was a moorland water, very soft, and contained much free oxygen; it had a most remarkable effect in creating the tubercles which were the subject of consideration that evening. When he first went there many miles of the service pipes were very nearly choked up. It was not a case of tubercles on the inside of the pipe; it was a case of the whole of the inside of the pipe being choked, with the exception, perhaps, of a small hole through the middle about as thick as a tobacco pipe. Miles of pipes had to be taken up because of the great difficulty experienced in clearing that material out from pipes as small as 3 and 4 inches in diameter. More recently he had adopted a method by means of which many miles of pipes were cleaned out, where the opening was as small as $\frac{3}{4}$ inch. He used the ordinary spiral-spring tube-scraper made by Messrs. Salter. That was connected with a swivel joint to the end of a length of gas-tubing, passed down a hole cut into the pipes in the street, and a gang of four men would clean 100 feet each way from that opening in the course of one night. That method had been adopted to a very large extent, and the cost of doing it in a 4-inch pipe was about tenpence a yard run. The great difficulty, which was experienced after the work was done, was that rust and peaty matter were found for a great length of time clinging to the inside bore of the pipe. In districts where the consumers lived in small houses not provided with baths, that did not matter very much, because they never noticed it; but in the residential districts, where the water was drawn into a white enamelled bath, it looked like coffee. In the latter districts the complaints had become so numerous that they avoided cleaning the pipes as much as possible, but it was still done in the poorer districts. With regard to the cleaning out of the larger mains, that

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had been done by means of the Glenfield apparatus, which was a pipe scraper similar to that which had been exhibited that evening, and it would do the work very effectually in town mains up to 12 inches in diameter. They had not yet ventured anything larger than 12 inches. They could pass the scrapers through from a half to three-quarters of a mile of a 9 or 10-inch main in one night, clean it out, and close it all up again, so that undoubtedly the process was capable of being applied on a considerable scale, and was one to which waterworks engineers and managers might profitably turn their attention. With regard to the formation of the material which coated the inside of the pipe, he regretted he could not follow Mr. Deacon in his very learned argument; but he had one or two instances to bring before the Institution, which would serve to show that the explanation which Mr. Deacon had given did not meet every case. At Sheffield they had a high-level main which, at its lower end, from which the supply to the outlying district was taken, was under a head of 400 feet. It was supplied from the high-level system of Sheffield where the water was peaty. There were three reservoirs, the water being decanted from the upper into the middle, from the middle into the lower, and then sent on its way for distribution. At certain seasons of the year the water went into the upper reservoir literally as brown as coffee, but when it went out at the lower one it was as clear as gin. Nevertheless that 15-inch main, 4 miles long, was coated from end to end with a beautiful, soft, velvety deposit which was nothing but peat. He regretted to have to differ from Mr. Deacon, but he had had that analysed, and about 96 per cent. of it was organic matter. There was a little iron which gave it its high colour, and when that main was scoured out cartloads of peat, exactly like coffee grounds, were removed. In certain parts on the upper surface of the main, tubercles had formed, which were nodules of iron mixed with organic matter. Going back for a moment to the old system of things in Sheffield, when he had first started cleaning out the pipes, he thought the deposit was due to the fact that the old pipes in Sheffield, in common with all other towns, had not been treated with Dr. Angus Smith's solution; but after a time it became necessary to deal with pipes that had been coated

with that solution, where tubercles were found in exactly the same condition as in the uncoated pipes. The late Mr. Thomas Hawksley had told him, as Mr. Deacon had also mentioned that evening, that he would most likely find a little pin-hole through the coating, which caused the tubercle to form. In hundreds of cases there was nothing of the kind; there was no perforation whatever through the glaze. The tubercle had been laid down upon the glaze, and in the Sheffield water at any rate it must have been laid down from iron which was in solution in the water, and not from the decomposition of the metal of the pipe. Here was proof positive—at the bottom end of that 15-inch high-level main there was a relief-valve made of gun-metal with gun-metal seatings, and tubercles were on the gun-metal. That settled it. They did not understand in the least how those tubercles were formed. He was delighted to hear Mr. Deacon suggest that there was a bacillus, or something of that sort, at the bottom of it, because they would now be able to make experiments. But in Sheffield (he limited his remarks to Sheffield) he had found with each tubercle that in the centre of it there was a hollow space containing the remains of a little bit of moss or a little bit of peat, and that round this centre there was spongy oxide of iron, so friable that, when it was taken between the finger and thumb, it left a mark similar to red paint. Outside that it got a little harder, and the regular decomposition of iron went on until at last the tubercles met, the material spreading completely over the pipe. Then came the difficulty with regard to the iron pipe; when the tubercles had met, how was the decomposition of the metal of the pipe to go on and to spread itself on the top of the tubercles; because that was the way in which the pipe got choked up. The resistance to the flow of water became at last so great that something had to be done, and the pipe scrapers were put to work. That was the process so far as his experience had extended, and he saw nothing to-day that differed from the action which took place 50 or 60 years ago. He had a 10-inch main in the lower part of the town laid nearly 36 years ago; that main now had the Angus Smith solution upon it perfect. Isolated tubercles had formed here and there.

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When that main was cut into, numerous pieces of the pipe had been brought to him so that he might flake the tubercles off. He found no pin hole, but he found isolated tubercles upon the glaze, the latter not being removed in the slightest. One process, which he had adopted as a matter of experiment, had given, except for the matter of cost, exceedingly good results. That was painting the pipes inside and out, instead of using Dr. Angus Smith's solution. He had found that when the pipes were coated inside with ordinary white paint (it was better to use an oxide paint, as ordinary white paint contained a certain amount of lead), that did more to keep off the deposit, as far as the experiment had gone, than even the best method of treating with Dr. Angus Smith's solution. At the same time, he did not attach too much importance to this, because if it were true that the oxide was laid down from iron which was in solution in the water, it did not matter what the pipes were coated with, the deposit was sure to come sooner or later. He believed it to be due simply to a mixture of oxide of iron with organic matter.

The President said he was exceedingly sorry to have to close that very interesting discussion, but the clock warned him that it must be stopped. They would be most happy to receive in writing any additions to the discussion, which might be sent to the Secretary, and to which Mr. Ingham would have the right to reply hereafter. He would now call upon Mr. Ingham to reply to the criticisms which had been already offered.

Mr. Ingham, in reply, said he was afraid he had not much to say on the remarks of Mr. Brunel, who had simply dealt with the scraper as worked in 1866. He would like to point out that his predecessor, Mr. Weeks, had done much to make the scraper a thorough success. When the scraper was first put through the pipes it was thought that it would be difficult to follow and locate it, but Mr. Froude, with his usual ingenuity, attached a large bobbin to the back end of the scraper with about half a mile of twine, or small rope, round it. The cord was marked, so that if the scraper stopped

Mr. Froude knew exactly where to find it by measuring over the ground. After the scraping of the first section, however, it was found that the noise was sufficient to locate the scraper easily. There were one or two points in Mr. Deacon's remarks with which he could not entirely agree, but speaking generally his ideas coincided with the author's so far as Torquay was concerned. Mr. Eaton gave his practical experience from another town, and he might be right as well. One could only deal with special instances. With regard to the acidity of the water, Mr. Deacon would be the first to admit that if oxidation took place there must be free oxygen present in the water, because this gas formed 30 per cent. of the whole weight of the nodule. Therefore the acids in the water must be broken up to free the oxygen, and in doing so, naturally the water would be neutralised and possibly turned into an alkaline solution. Again, it took five hours for the water to flow through the main from the intake to the Chapel Hill reservoir, and that, he thought, would give sufficient time for the chemical action to take place. With regard to the very small pin-point to which Mr. Deacon had referred, he quite agreed that this was correct as far as Torquay was concerned, and especially with reference to the new main which was coated. In scores of instances he had found a very small point underneath the centre of the nodule, whereas in the uncoated pipe quite a different action appeared. The nodule in that case, instead of being hollow, was generally formed evenly over the pipe. It did not commence from one small point alone and work from that, but started in several adjacent spots which worked together as the nodules grew larger. The nodule was flat underneath, whereas in the coated pipes there would be a semi-circular space under the centre of the nodules. This was not the first time that he had heard of the iron microbe. He believed that Mr. Deacon was one of the first to put that theory before the general public, and there appeared to be something in it. At the Antwerp water works they had had a certain amount of trouble caused by the microbe action on the pipes. He had never seen the new machine which had been brought to their notice that evening, Plates 136, 137, but, with Mr. Deacon's usual inventiveness, they might rest

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assured that he would not be satisfied with anything that was on the market. Like his waste-detecting meter and Vyrnwy outlet-valves, it was a great improvement, because the whalebone would not injure the coating like the knives of the scraper, Fig. 3, Plate 131. Mr. Hawksley had made some remarks on the theoretical and actual delivery (page 510). In the first place, Mr. Box had taken very careful gaugings of the delivery, and found that Prony's formula gave as nearly as possible the exact delivery of the pipes when first laid. He had based his information upon this as to the amount of iron lost from the pipe, by comparing the discharge obtained by Box with the actual gaugings now obtained after scraping. Oil-proving was a successful way of dealing to some extent with corrosion, but he thought that the firms in the country which went in for oil-proving might be counted on the fingers of one hand. It was generally water, water, water, when tenders were sent in. Mr. Eaton's price for scraping at Sheffield appeared rather high compared with that at Kendal. Mr. Ritson, the engineer of the Kendal water works, gave his price at $6\frac{1}{2}d.$ per yard run, whereas Mr. Eaton's cost $10d.$ He did not know whether that was due to the different methods employed; if it was, he would recommend Mr. Eaton to consider the Kendal method. With regard to the Glenfield scraper, if that were compared with Mr. Appold's original one, it would be found that there was very little difference between them. The credit of scraping pipes with a machine worked by water pressure was without doubt originally due to Mr Appold. He had heard it said that Mr. Kennedy was the inventor, but if the dates were compared it would be found that Mr. Appold was in the field before him. At Plymouth, where they had a similar water to that at Torquay, Mr. Sandeman had recently scraped a 24-inch main with very great success, and had obtained an increase of something like 36 or 37 per cent. That was only done about a week before the Plymouth Meeting. As to the tubercles upon gun-metal, was Mr. Eaton quite sure they were not deposited from the iron nodules, which had already formed in the pipe a little higher up, and which might have been carried down by the water and deposited on the gun-metal? He was very pleased that they had had such a good

discussion, and only regretted that there was not more time available to go into the matter.

The President said that he was neither an authority on the incrustation of pipes nor on the construction of scrapers, but, listening to that very interesting discussion, he had reached one conclusion which he thought would commend itself to all Members of the Institution, namely, that whatever might be the cause of trouble in water mains, the mechanical engineer was looked to as the person to put things right, and in all great schemes for water supply the mechanical engineer would be very much in request. He had already, on behalf of the Members, conveyed their thanks to Mr. Ingham for his very interesting Paper, and he was sure that they all anticipated, when the Proceedings were published, that the discussion, which had been necessarily abridged, would be considerably enlarged in the form of correspondence.

Communications.

Mr. H. W. Pearson, chief water engineer of Bristol, in sending for exhibition at the Meeting two pieces of pipe, 5 inches and 6 inches diameter, Plate 134, which had been in use over fifty years, wrote that the 6-inch pipe was most probably laid about 1842, being part of the work of a small company which existed in Clifton, prior to his company coming into existence in 1846–47, and which they took over upon incorporation. This pipe was taken out broken when repairing the main at the bottom of Richmond Park Road, Clifton, on 6th October 1899. The 5-inch pipe was laid as one of the first lengths under the Company's Act some time in 1847–48, and was taken out at Broadmead, when renewing mains on 16th October 1899. These pipes showed a fair state of preservation, and were not much corroded internally. There was a certain internal coat of carbonate of lime and oxide, mostly the former, and some nodules which had been formed in an unaccountable way, probably due to a foreign substance forming an excrescence in the pipe round which the lime has clung ;

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or perhaps there might have been a blister or sand-blow in the casting, but it did not seem to have increased beyond a certain size.

Mr. John Barr wrote that he quite agreed with the author's statement (page 481) that, when laying pipes, the jointing should be carefully watched to see that no lead finds its way into the pipe, as badly run joints form the most serious and the most frequent obstruction found in scraping. On page 484 he had furnished some additional particulars of pipe-scraping carried out at various places since reading his Paper to the Institution of Engineers and Shipbuilders in Glasgow in March 1897.* One of the staff of the Glenfield Co., Kilmarnock, had just completed the superintendence of scraping about fifty miles of pipes, varying in diameter from 9 inches to 5 inches, for the Tarapaca Water Works, Chili. The final results as to increase of delivery had not yet been ascertained, but temporary gaugings had shown an increase of about 25 per cent. It was interesting to observe from page 487 that air-valves had the effect of decreasing the amount of corrosion. It was getting to be more usual to put down hatch-boxes when new mains were being laid, thus saving considerable cost and inconvenience, when scraping operations had to be carried out.

Mr. Henry Nicholson wrote that the author stated (page 479) that the old main of 10 inches diameter was laid in 1858, at a time when Dr. Angus Smith's coating was not known. But Dr. Angus Smith took out his patent † in 1848, claiming "the coating the interior of water pipes with coal tar by the aid of heat," and he had told the writer that it came very rapidly into use.

He did not quite see what the miscellaneous list of articles found in water pipes had to do with the subject of incrustation (page 481). To his mind it was simply a matter of negligence in not

* Proceedings, Institution of Engineers and Shipbuilders in Scotland, 1896-97, vol. xl, page 201.

† 1848, Patent No. 12,291, and reprinted in 1885.

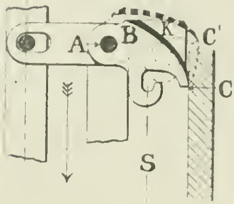
seeing that the mains were kept free from such obstructions when laid. He thought that, if more attention were given to the fixing of proper wash-out pipes (see sketch) in small mains, at the bottom

and ends of the pipes, and the flushing of pipes took place at frequent intervals, the main would not get reduced in its discharging capacity, due to incrustation, so quickly as the author had stated. There was no doubt considerable room for improvement in coating pipes at many of the foundries in England (page 497). At the same time, if good materials were used in the bath, and care were taken to see that the pipes were perfectly smooth inside and out, and free from rust, sand, blacking scabs, &c., a good coating would be obtained by putting the pipes into the hot bath, and allowing them to remain there about one hour, then withdrawing them very slowly. By this process the life of the coating would be considerably lengthened, and incrustation would not form so rapidly. In the writer's opinion, the scrapers shown by the author should not be used, as they would destroy the coating.

Mr. G. William Lacey, water engineer of Oswestry, wrote that the Paper was very interesting and instructive to those who had, or might have, any main scraping to do. He had had occasion just recently to scrape a short length of 544 yards of 7-inch main, which had not been done for five or six years. This was below the service reservoirs, and was in a very bad condition, such that the capacity of the pipe was reduced to the equivalent of slightly more than $5\frac{1}{2}$ inches diameter, the nodules of incrustation being very large. The cost of this scraping had worked out at $4{\cdot}76d.$ per lineal yard. Some of the main scraping on the pipe line from the storage to the service reservoir compared as to cost with the author's lowest figures, namely, $\frac{1}{10}d.$ per yard (page 483), this main being scraped thrice yearly. The cost named included at least two journeys of the scraper through the main on each occasion, the staff employed being the water inspector and four men. The water supplied to Oswestry is an upland water from Denbighshire, and a considerable quantity of peat is brought down.

— Mr. William Schönheyder wrote that the newest type of scraper, the "Froude," Fig. 3, Plate 131, was in his opinion of faulty design, inasmuch as the scraping knife K was hinged at a point A, Fig. 17, situated between itself and the centre line of the machine. The effect of this arrangement is that the cutting edge of the knife will only fit the pipe in one position, namely, when the spiral spring S has pulled it full up against the provided stop, as shown in full line of the accompanying sketch, Fig. 17. When, however, an extra resistance is met, the knife K is thrown back, as shown dotted, so that the portions of the edge marked B will recede from the pipe, and the pointed part of edge marked C, Fig. 17, will be forced hard against the pipe, thus cutting an acute-shaped groove in the incrustation, and possibly even in the pipe. The amount of bad scraping or of damage done will of course depend on the relative adjustment of the spiral spring S and of that which forces the knife out radially; the weaker the former, and the stronger the latter, the greater will be the harm done, and the maximum harm will be done if a spiral spring breaks, for then a continuous groove (though very obtuse) will be cut, unless the knife can fold back to be completely out of the way. In the actual machine shown, the spiral spring S appears to be much the stronger, and probably no harm may as yet have been caused, but the danger is always present. The direction of movement of point C, when the spring yields, is towards the point C¹.

Fig. 17.



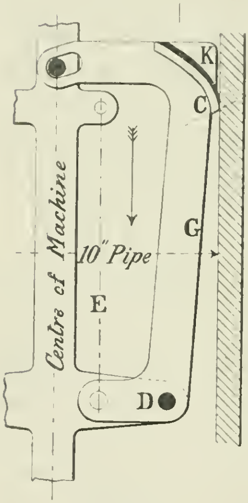


Fig. 18.

If the knives were hinged at fulcrum D, Fig. 18, and were held up to their work by the spring E, they would, in giving way to

extra resistance, move in a nearly radial line towards the centre of the pipe, and the scraping edge would practically always fit it. A slight slope of the scraping edge, as shown at C, would cause the knife K to give way when meeting the end of a projecting ferrule, &c., and yet would not prevent the proper cleaning, if sufficient tension had been put on the springs. The sloping edge G of the knife bar would help the knife out of a large branch pipe, if it had entered one.

The cup leathers for pushing forward the machine appeared to have suffered severely, as is natural from their thinness, about $\frac{1}{4}$ inch, and the great space between the piston plates and the pipe, about $\frac{1}{2}$ inch all round. If this large clearance is necessary, the cups should have been at least $\frac{3}{4}$ inch thick, if made of leather; or they could be made of thin steel, slit up at the edge like the supplementary scraper now used, and made approximately tight by internal rubber cups.

Mr. A. Tannett Walker, Vice-President, who was present, but did not speak owing to the lateness of the hour, wrote that iron and inorganic substances were particularly liable to incrustation by deposition of carbonate of lime in solution from water; the slower the running of the water, or the period of rest, the quicker was the deposition of incrustation. It deposited itself in layers of a sub-crystalline kind at right angles to the base or original substance; when in round iron pipes the crystals were compelled to lessen in size owing to decrease in diameter; when in a square pipe the crystals were built up similarly square from each side, and it was remarkable that they would not unite with each other at the corners. The wrought-iron $1\frac{1}{2}$-inch internal diameter tube, Plate 134, had been reduced to $\frac{5}{8}$ inch diameter by incrustation in four years' time; this pipe was taken from a colliery near Leeds, and it was used for conveying drinking water down the pit for the horses. A very old wooden pipe from Garsforth Colliery, used for a similar purpose, contained the incrustation shown in Plate 134 the corners of which would not unite; the Glasshouton incrustation was from another wooden pipe used for a similar purpose. He had found from

(Mr. A. Tannett Walker.)

experience that Dr. Angus Smith's composition would, on an average, give 50 per cent. longer life to a pipe. He had seen a non-coated 4-inch pipe recently taken up in Leeds, having been laid down in 1858, which was almost solid with incrustation. He had generally found that wrought-iron pipes incrusted more quickly than cast-iron pipes, examples of 1½-inch wrought-iron pipes having been reduced to half their size in five years.

Mr. Joseph Parry, water engineer of Liverpool, wrote that an excellent short history of Dr. Angus Smith's pipe coating is given on pages 143–5 of the "History and Description of the Manchester Water Works," by the late Mr. J. F. la Trobe Bateman. Mr. Bateman attached great importance to the observance of the condition that, before dipping in the Angus Smith mixture, every pipe should be painted inside and outside with linseed oil as soon as the sand had been brushed off, and while the pipe was still warm. The writer was, however, doubtful as to the utility of the linseed oil, excepting so far as it might have the effect of preventing the formation of rust between the time of the casting being taken out of the pit and the time of dipping. The failure in many cases of the coating to retard incrustation to the extent originally promised was no doubt due to neglect of the instructions contained in Dr. Angus Smith's specification, and further to the change that had taken place in the quality of the pitch that was used. Formerly it was the practice to allow the anthracene oils to remain in the pitch. Now that anthracene had become a valuable commodity for the production of dyes, the process of distillation was pushed beyond the point at which anthracene was carried over. In that way there had been brought about a deterioration in the quality of pitch which had, the writer believed, greatly lessened its value as a preservative of iron.

Mr. Deacon had described the earlier stages of certain operations for dealing with obstructions in the Vyrnwy pipes. Since then the writer had put down an experimental plant, suggested by Professor J. Campbell Brown, to determine the effect upon the deposits of

neutralizing the acidity of the water. In connection with this plant the writer had laid two short lines of pipes treated in various ways in regard to coating. Some of the pipes were uncoated; some coated once in the ordinary manner; others twice coated; and others painted with linseed oil before being dipped, as recommended by Mr. Bateman. One set of experiments had been completed, and another set started, but some time must yet elapse before definite results could be given.

That the formation of nodules or barnacles on iron exposed to the action of air and water could be effectually prevented by a coating of artificial asphalte similar in effect to the Angus Smith composition, might be inferred from the following example. In the year 1853 the late Mr. Thomas Duncan erected in Liverpool for a high-level service a circular cast-iron tank with vertical sides, 75 feet in diameter and 10 feet in depth. The sides and bottom were covered with a coating of pitch, from 1–16th to 1–8th inch thick, probably applied with a brush, but the precise method of application that was adopted could not now be discovered. During the forty-five years that had elapsed since the coating was put on, soft water from the Rivington works had been daily pumped into the tank, and the water level had been constantly rising or falling, according to the fluctuations of demand upon the service. The coating and the iron under the coating were as perfect to-day as when the tank was built, and there was not the least sign of incrustation. Therefore, on the question of the origin of the nodules, referred to in the Paper and discussion, the writer was of opinion that the action was entirely chemical and not at all bacterial.

Sir Frederick Bramwell, Bart., Past-President, wrote that a 5-inch main, $1\frac{3}{4}$ miles in length, in the Reigate section of the main belonging to the East Surrey Water Co., had been scraped by one of Blakebrough and Sons' scrapers, with the result that the pressure at the pumping engine, which used to be 215 lbs. per square inch, was reduced by 28 lbs. The pressure due to the statical head was

(Sir Frederick Bramwell, Bart.)
135 lbs. The pressure due to resistance, therefore, was as much as 80 lbs. per square inch, diminished by scraping to 52 lbs., or a reduction of 35 per cent.

Mr. Ingham wrote that he accepted Mr. Nicholson's correction (page 518) with regard to the date of Dr. Angus Smith's patent, but he was inclined to think that it was not well known till many years after the date mentioned, 1866. The miscellaneous articles referred to had of course nothing to do with the corrosion, but they had a very damaging effect on the scraper when first sent through a line of main.

Although washing out was of considerable benefit, especially locally, it could never take the place of scraping in districts that had a very soft water-supply. The scrapers certainly had a detrimental effect on the coating, but when once a pipe had got into such a bad state as to require scraping, it was very little use to consider the coating. The main question was the removal of the incrustation, and a steel knife did it well. At the same time it must not be overlooked that, when scraping was once commenced, it had to be continued at short periods, so there was very little to be gained by having a flexible knife, which perhaps did not injure the pipe so much, but had not the lasting properties of steel.

After having carefully examined the sketch accompanying Mr. Schönheyder's remarks (page 520), it was not apparent what advantage would be gained by making the alteration shown in Fig. 18. If the knife was in a fixed position radially, and allowed a backward movement only, the improvement suggested would be a good one. Since, however, a large amount of play was allowed in the slot to the left of pivot A (Fig. 17), there was no reason to suppose that the knife had the cutting or grooving action referred to. The radial and backward movement only took place upon meeting with an obstruction which needed a much greater force than that required to remove the nodules. In Fig. 18 (page 520) a very much stronger spiral spring would also be required at E than at S in Fig. 17, and the tendency would be to shear pivot D when C (Fig. 18) came into contact with an obstruction.

The cup leathers referred to (page 521) were straight when new; and $\frac{1}{4}$-inch leather was found sufficient for the work. Thin steel plates were not as pliable as leather, and would not recover their shape like the latter when damaged. In fact there was very little trouble with the Froude scraper, and it was inadvisable to make alterations in a machine when there was nothing whatever to be gained by it.

The Institution of Mechanical Engineers.

PROCEEDINGS.

November 1899.

The November Meeting of the Institution was held at Storey's Gate, St. James's Park, London, on Friday, 24th November 1899, at Eight o'clock p.m.; Sir William H. White, K.C.B., LL.D., D.Sc., F.R.S., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The following Paper was read and discussed:—
"Openings for Mechanical Engineers in China"; by the Right Hon. Rear-Admiral Lord Charles Beresford, C.B., M.P.

The Meeting terminated at a Quarter to Ten o'clock. The attendance was 228 Members and 197 Visitors.

OPENINGS FOR MECHANICAL ENGINEERS IN CHINA.

By the Right Hon. Rear-Admiral
LORD CHARLES BERESFORD, C.B., M.P.

The President desired to say, in introducing the lecturer, that the Institution of Mechanical Engineers, and himself in particular, were deeply indebted to Lord Charles Beresford for undertaking, in the midst of many pressing engagements, the Paper to which they were about to listen. Perhaps he should explain that he took Lord Charles Beresford at some disadvantage when he asked him to undertake this task. It was after their dinner in the Spring, and Lord Charles was in a very good humour. Some after-dinner promises were not fulfilled. That promise had been kept, and he was sure it would be a matter of the greatest interest and advantage to them, that a gentleman of large experience of the world and keen insight should give them his views about Openings for Mechanical Engineers in China.

Lord Charles Beresford said he must take exception to one of the President's remarks as to his being only in a good humour after dinner. He belonged to the Irish race, and he thought they were generally in a good humour at all times of the day. When Sir William White asked him to read a Paper he accepted with great diffidence, because he was not a mechanical engineer, and he was not a trading or a commercial man; and he believed it was the first time that any gentleman outside the Institution, who was not a mechanical engineer, had ever read a Paper at their meetings. Therefore he assured them that he regarded it as a very great compliment to himself, and he only hoped that the remarks he would make in the Paper would be useful for the object they all had in view, namely, the furtherance of British trade and commerce in China.

PAPER.

Although the civil engineer must first clear the way, there is great scope even now for the mechanical engineer in China, and the future offers an almost unlimited field of operations. Imagine an empire which, with its dependencies, covers an area of over four and a quarter millions of square miles, see map on Plates 138 and 139, and has a population of nearly four hundred millions of people, and then conceive this vast territory and this multitude of people still pursuing the arts and industries with the primitive tools, methods, and ideas of two thousand years ago. The vista of untapped possibilities for the modern engineer is seen to be extensive and very promising. I propose in this Paper, which your President and Council have paid me the compliment of inviting me to read to you, to divide the principal openings for the mechanical engineer under three heads, and to touch shortly upon each.

I may class them as follows :—

I. Railways and electrical engineering.

II. Mining and allied works.

III. Manufactures.

Under the first of these headings I venture to suggest that the immediate development of China will most rapidly proceed. As already shown in my book, "The Break-up of China," at the date of my visit, which was the beginning of this year, 317 miles of railway had been completed, 2,270 miles were building, 2,507 miles were projected, and had been or were then being surveyed by the pioneers of your profession (the civil engineer), and 1,070 miles had been projected but no surveys had yet been made; so that altogether in the next few years we ought to see over 6,000 miles of track laid, and a new and important department will have been created for the mechanical engineer in building, running, and repairing the locomotives and other rolling stock used by the Chinese and foreign proprietors of these railways. I may mention that the energy, the pluck, and the signal abilities of Mr. C. W. Kinder, Fig. 3, Plate 140,

a great personal friend of mine, with whom I stayed in the north of China, and who is a distinguished ornament to your profession, have already led to the erection of most extensive works at Tongshan, Fig. 5. These works construct all their rolling stock except locomotives, and were engaged on the first engine ever attempted to be built for a railway in China at the time of my visit. Mr. Kinder estimated to be able to build engines at a cost of £1,600 which would cost £2,850 at home, but the latter could not have been delivered in China under a twenty-four months' delivery. His greatest difficulty is the lack of skilled labour, although he pays good wages. The Russians, who tempted some of his engineers away, are now paying less than Mr. Kinder, and he told me that the men wanted to come back to him. The mechanical engineers were British, whom the Russians succeeded in getting away from Mr. Kinder. There were only four of them, and he intimated to me that he was not very sorry to lose them. The engines already running on the Shan Hai Kwan Railway were made by Messrs. Dübs of Glasgow and Baldwin of America. The American engines are not so good as the British, but are quite good enough for the work. The Americans use steel instead of copper or brass for fittings, and the axle, instead of being one piece of metal turned so as to leave a solid collar for the wheel, is made in three parts—an axle and two collars; that is to say, the collars were separately made and screwed on to the axle. The idea that skilled native labour is cheap is quite fallacious, as far as North China is concerned, the native workmen getting 60 dollars a month, or about £6. During the twelve months prior to my visit two locomotive boilers had been replaced and four re-tubed, while five locomotive fire-boxes had been replaced with the assistance of native labour. I may say with regard to this question of engines that I asked Mr. Kinder, who is a very patriotic British subject, why he employed the American engine, and he pointed out that the price was so very different, and that the delivery was in four months as against twenty-four. As he remarked, if he ordered thirty engines he would save something like £30,000 on his capital account, besides which he would be running his plant sooner, and so sooner be able to make a

dividend, and by earning money be in a position to extend his line. Under such circumstances he thought it was in the interest of those who employed him to take the American engine instead of the British, and I believe you will think he was right. Mr. Kinder estimated that the 300 miles of rail to Shan Hai Kwan cost for everything about £6,000 per mile, including the admirably fitted workshops I saw at Tongshan, a view of which is given in Fig. 5, Plate 140. Close to the machinery shops were some cement works, but the machinery was rusting and doing nothing. These works had been started by Chinese, but, owing to their curious inability to undertake mechanical or manufacturing work without European supervision, the works had been a failure. Mr. Kinder told me that the railway alone took 60,000 to 80,000 barrels of cement a year, and there was a great demand for it elsewhere, but the cement works were now closed.

In addition to the labour difficulty, which can be easily overcome when skilled mechanics realise the advantages offered to them in China, there is also another difficulty to contend with—the Chinese hatred of the "foreign devil," as they call all Europeans and Americans. There was some rioting and ill-feeling at the time of my visit, and two of Mr. Kinder's engineers were fired at, and also badly beaten at Fungti. As an example of the futility of British methods in China—I am speaking of Foreign Office methods—my attention was drawn to the fact that, instead of at once demanding the punishment of the ringleaders, and the withdrawal of the Chinese Kan Suh troops who were responsible for the outrage, the British authorities summoned a conference of the whole of the Foreign ministers, and as a result of their united action two of the offenders were mildly whipped, receiving exactly the same punishment as some coolies who damaged a pump-handle and a piece of hose-pipe (total value 2 dollars) a few weeks before. I mention this because I think in that sort of question it would be wiser if our Foreign Office took the whole responsibility if a British subject suffered. If the representatives of foreign Powers are consulted, they naturally are not interested, and in this case did more harm than good, the united efforts of the representatives of the Powers resulting in a slight whipping being administered to the

culprits; whereas if the British authority had put its foot down and had been well backed up at home, those men would not have received so slight a punishment, and our people would not have been laughed at by the Chinese. Mr. Kinder was so dissatisfied that he at once withdrew his engineers on his own authority, and the soldiers, emboldened by the mild treatment awarded to their comrades, proceeded to damage winches and boilers at Pei-ho-tien, and to strip off some copper tubing. That was the result of the mild whipping. The matter was, however, soon afterwards settled owing to the British authority acting alone, and the Kan Suh troops withdrawn.

Railways are the greatest, easiest, and speediest instruments of civilisation, and I look forward with confidence to the benefits which will accrue to China, and to British trade and commerce, by the opening of the country in this manner. The mechanical engineer has a great part to play in the near future when Stephenson's "iron horse" penetrates into the "Middle Kingdom," and I should strongly recommend this Institution not to overlook the great possibilities before them in this direction.

I have placed electricity under the first heading, because I learn from the ordinary channels of information that since my return from China it has been rendered possible for the traveller to go from the railway station to the gates of Pekin by electric traction. I, personally, was carried into the city in a mandarin's chair, while my staff rode on Chinese ponies, and judging by the then state of the roads, to have so soon laid and started an electric tramway is very creditable to the promoters of the enterprise. I can give you some idea of a Chinese road. Two thousand years ago the roads and canals in China were perfect, but since that time, judging from their appearance, I do not think they have ever been repaired. Complaining to an American gentleman about it, the latter said: "Yes, sir, they are very bad. There was a mule drowned in the road outside my Embassy." He meant in one of the deep puddles.

In the European settlements electricity is already used for lighting purposes, and even at Hankow, six hundred miles up the Yangtse River, some firms were laying down electrical plant.

The abundance and cheapness of coal will render this branch of industry—electrical engineering—very profitable in a short time. The Chinese of the better class are very fond of luxury after European modes, and I have no doubt that they will be ready consumers of electrical power for lighting and manufacturing purposes. Of course all the plant must in the first instance be imported; and I would like to point out to this Institution that we are very far behind Japan and America in the use of electrical power, and unless we are much more energetic the vast electrical plant which China will require will surely come from those countries. There is also against us the fact that those countries are much nearer to China, and therefore the freight will be cheaper. It is more than probable that Japanese and American engineers who accompany the plant to China will be employed there instead of British engineers. I have shown examples of this in my book, "The Break-up of China." At Kioto, in Japan, I saw the great electrical plant which, in addition to lighting two-thirds of the town, also supplied the motive power for the city trams, for the pumping machinery at the water works, and for no less than sixty different industries in or near Kioto. The electric energy is produced by water power from a fall of 120 feet. The plant is chiefly American or German, but the Japanese are now beginning to make their own.

There is another place near Kioto, having a great trade from the sea through the Biwa Lake, and up a stream. The total distance is about 65 miles from the sea to the point of destination. About 30 miles up this river, which is navigable, boats brought the passengers and their trade. Then they had to trans-ship to coolies, and carry up an incline of a mile to another stage, where the cargo and passengers were again re-shipped and carried on to Lake Biwa. The Japanese had an electric tramway with a steel cable, and the boats were floated into a cradle, hauled up this mile, and then put into the water again, continuing their journey without discharging cargo or passengers. This was entirely a municipal enterprise. The charge was extremely low; the tramway had already begun to pay itself back on the initial capital expense, and had increased the

trade and commerce about tenfold on account of the celerity on the line of communication.

Speaking of the Japanese, there is an idea in this country that the Japanese do nothing but copy. They do copy, but they copy the best they can find in all nations. But they have their own inventive genius most strongly developed. A large number of them have naturally got the common-sense which mechanical engineers always possess, and at this moment they have what I consider—knowing something about it—as good a quick-firing field artillery gun as there is in the world. Parts of this gun are German and parts are British, but the whole of it is manufactured in Japan. It is essentially different from all other guns. They have also as good a magazine-rifle as there is in the world, and the whole of their army is equipped with it. Parts of that rifle are copied from other nations, but the whole of it is Japanese and manufactured in that country, and essentially different from European rifles. From what I saw of that rifle—and I saw them practising with it—I think it is as good a rifle as there is in Europe. That is a thing to note as showing how clever the Japanese are in their own minds as far as inventive genius goes.

In the United States, at Buffalo in particular, I saw a similar display of ingenuity and enterprise. The magnificent Falls of Niagara are utilised to produce electrical power for hundreds of industries at the small cost to the consumer of £1 per horse-power per month, which is not an extravagant charge to a man working a small manufactory, who has no stoking to do, and no trouble with leaky flanges, boilers, or anything else. He has only to switch on in the morning and commence work straight away.

Of course Japan and America have had a great advantage over older countries like Great Britain, in the fact that it is far cheaper to start with the latest products of electrical engineering than to replace steam, gas, and other expensive systems already laid down, as we in this country have to do. The reason I have referred to this is, that China is in the same happy position as Japan and America, and the electrical engineer will have many openings before him if Institutions like this will study the immediate needs of China, and

assist its members to make use of their experience, industry, and ability.

Telegraphs already exist all over China, and are the Government property. Having said that, I need not say that they are very badly managed. I was credibly informed that it is often possible to go from Pekin to Tientsin and thence to Shanghai, and to arrive before a telegram you had despatched at starting. I do not think that sounds very creditable to the Government management of telegraphs. By paying treble rates it is possible to get reasonable speed, but the service is very inferior. Telephones exist in some of the settlements, but one manager of a telephone company in China told me that all their copper wires were stolen by the Chinese, so that they had a very inefficient service with steel wires. In Japan I was very much struck by the immense use that all the shopkeepers and offices make of the telephone. In all the streets of the small towns of Japan there are telephone posts with twenty, thirty, and forty wires attached to them, and used every day by the Japanese people. It astonished me very much to see a country so young as that taking advantage of so useful a line of communication.

II. *Mining, etc.*

The mechanical engineer who has adopted that branch of his profession which has to do with mining machinery, boring machinery, hydraulics, and allied works, will find that there is plenty of scope for him at this moment in China. The country is full of minerals; coal, iron, gold, silver, copper, mercury, lead, and salt, are all to be found in paying quantities, and only skilled workers and the latest machinery are needed to develop the rich resources of this marvellous country. Labour can be had for mining work at the ordinary coolie pay of 200 cash, about 5½*d.* a day. The Russians are probably much alive to the mineral riches of Manchuria, where an Englishman showed me specimens of gold obtained by himself in the interior; and another Englishman, who has lived for years in the country, told me that Manchuria was a white man's country, very healthy and bracing, and with a climate, soil, and resources closely resembling

Vancouver. But Manchuria is not the only place where minerals are found. All over China there are great deposits. I need only allude to the marvellous coal fields of Shansi, with seams 80 feet thick, which the Pekin Syndicate are about to work. I have heard—I do not know whether it is true—that the Pekin Syndicate are going to work this marvellously rich locality without the usual Government guarantee. If they are going to do it I wish them every success, because it is a very plucky enterprise. My own belief is that they will be able to do it if they have got some of the Chinese authorities themselves to put some money into the Syndicate. Then I think it will probably go very well, and there will not be the usual cry against the "foreign devil." If they are going to do that, it is the first time in which British capital of any character has been invested in any enterprise in China without a guarantee from the Chinese Government. I look forward with great hopes to this enterprise. I hope other companies will do the same thing; and when once we get our vested interest in that country I think that our people will see that they are looked after. I must allude also to the resources of Shantung, where I have seen a German missionary map marked in all directions with notes of gold, coal, iron, and other minerals; also to the coal fields and iron mines of Hanyang, and other places on the Yangtse, and the many other districts where minerals have been found, to show that the riches of China in this direction are incalculable. I may say that I visited as many places as I could in the time—I think four—where coal was to be found. I went to the Hanyang mines and saw the coal and the iron ore. I went to other mines where the coal was literally on the surface, and the Chinese were picking it up with picks and shovels really from the surface. There was no shaft of any kind there, and the coal was taken out of holes only 3 or 4 feet deep. It was excellent coal, which they put in baskets and sent down the river about forty miles from the place. The price asked for it there was prohibitive, so that the people could not buy it, but it will show what possibilities there are when once there is a proper transport service and proper mechanical efforts for raising the coal, and for transporting it about the country. All these vast stores of underground wealth belong to

OPENINGS FOR MECHANICAL ENGINEERS IN CHINA.

Fig. 1. Map of China.

Continued on Plate 139.

Area and Population of the Chinese Empire.

China Proper.

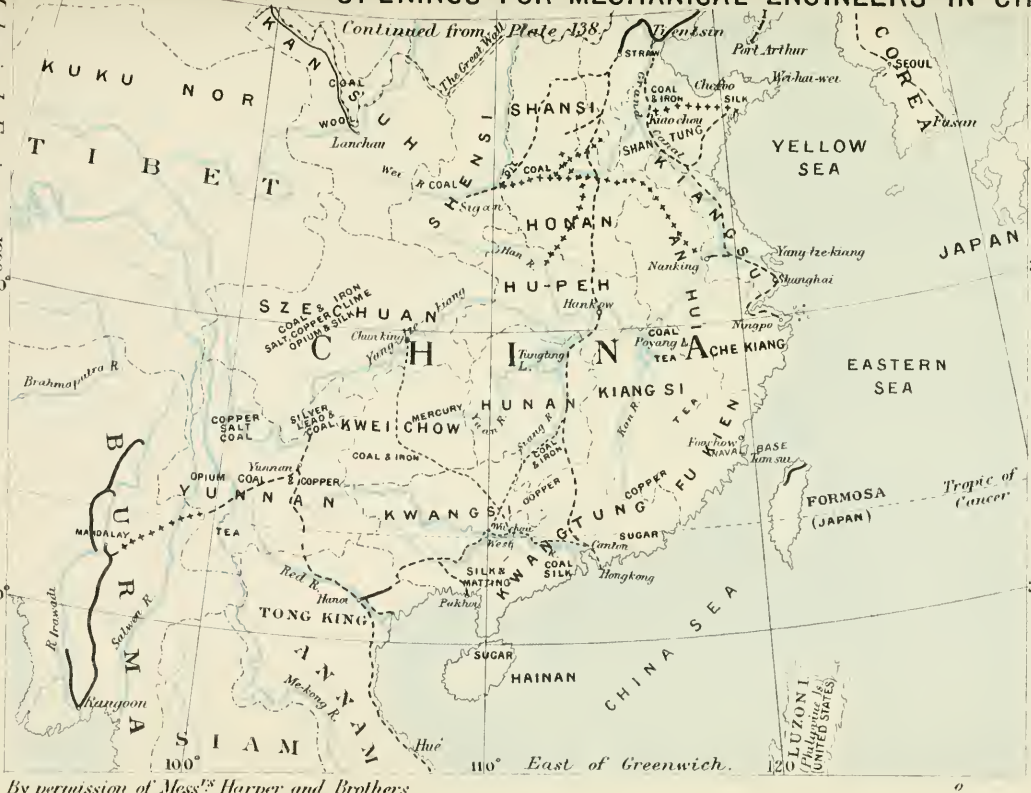
	Area Sq. Miles	Pop
Chihli	115,832	19,350,000
Shansi	81,854	11,200,000
Shensi	75,291	8,300,000
Kansuh	125,483	9,300,000
Shantung	55,985	25,000,000
Honan	67,955	22,100,000
Kiangsu	38,610	21,000,000
An hui	54,826	21,000,000
Hupeh	71,430	30,000,000
Kiangsi	69,499	24,600,000
Hunan	83,398	21,000,000
Chekiang	36,681	11,800,000
Fukien	46,332	20,500,000
Formosa	13,330	3,000,000
Kuangtung	86,873	27,700,000
Hainan	13,166	2,000,000
Kwangsi	77,220	5,200,000
Kweichau	67,182	7,700,000
Yunnan	146,719	12,000,000
Sze chuan	218,534	45,500,000

Territories Outside China Proper.

Manchuria	363,720	7,500,000
Mongolia	1,300,000	2,000,000
Sinkiang	548,500	1,000,000
Tibet (including Koku Nor)	533,360	1,500,000
Total	4,291,780	360,250,000

Railways open ————
" building ⊢⊣⊢⊣⊢⊣
" surveyed + + + + +
" proposed - - - - - -
Russian Military Camps ●

OPENINGS FOR MECHANICAL ENGINEERS IN CHINA.



By permission of Mess.rs Harper and Brothers.

Fig. 2. Map of China.

Treaty Ports.

Amoy	Ningpo
Canton	Pakhoi
Chefoo	Samshui
Chinkiang	Shanghai
Chungking	Shashih
Chung Tsin Sho	Soochow
Foochow	Ssumao
Hangchow	Swatow
Hankow	Tientsin
Ichang	Wenchow
Kiukiang	Wuchow
Kiungchow	Wuhu
Lungchow	West River Stages
Mengtze	Yohchau
Nanning	Yangtze Stages
Newchwang	

GREAT BRITAIN

on same scale.

Area 88,094
Pop. 35,275,000

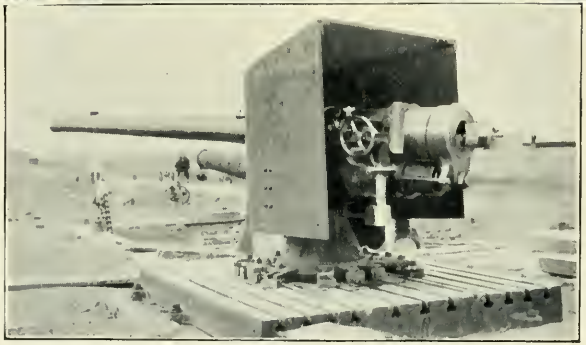
OPENINGS FOR MECHANICAL ENGINEERS IN CHINA.

Fig. 3. *Hand Trolley.*

Fig. 4. *"Rocket of China."*

Fig. 5. *Machinery Shop at Tongshan.*

Fig. 6.
4·7" Quick Firing Gun,



made at Shanghai Arsenal entirely of Chinese steel.

Plate 140.

the Chinese Government. Imagine the British Government owning all the mines in this country, and charging a handsome royalty for the right to work them, it will then be seen how great are China's undeveloped sources of revenue.

The mining engineer must necessarily understand all about pumping machinery and hydraulics, and if at first there is little opening for him in his proper sphere, I should suggest that he made use of his knowledge in another direction. There is a great field for mechanical engineers in most of the old and all of the newer concessions and settlements in supplying water to the European community. At a place like Hankow, for instance, where there are no water works at all, there is not only the European community, but the Chinese on the other side of the river who will be glad of water works. At present all water has to be boiled before use, and is even then unpleasant. There is a project for supplying Canton with water, which a countryman of mine, a former Member of Parliament, is now actively engaged on.

For mining machinery, engines, pumps, and all other plant of this description, there is a great demand, and only capital and British mechanical engineers are needed to give a great impetus to British manufacture of these goods.

III. *Manufactures.*

The abundance of coal and iron in China makes it absolutely certain that China will some day become a great competitor with us in the industrial market. But so far from fearing this competition, British manufacturers should reflect that if they are wise, and take time by the forelock, China will for many years to come be an enormous buyer of machinery, tool steel, and other manufactured articles, while, before the necessary re-action can come about, and we begin to feel the effects of her competition, China will have become so rich, or should have become so rich, that the increased amount of our products which she will take in one direction will counterbalance our losses in another. There are other points for us to remember.

2 P

I. A poor country can never buy very much from other nations.

II. Supply creates demand, despite the seeming paradox; and

III. The volume of trade keeps increasing even if individual industries suffer. To explain what I mean.

I. If China is a good customer of British goods now, she will become a better customer still when she has more money to pay for her increasing necessities. She can only get this money by exploiting her minerals and becoming a manufacturing country with large exports. The richer China becomes, the more she will become a purchasing Power.

II. Again, it is an undoubted fact that an increase of supply increases the demand for an article. This partly arises from the increased supply cheapening the cost both to the manufacturer and consumer. The introduction of machinery, although at first opposed by the more ignorant, has thoroughly proved this, especially in the case of Arkwright's invention of the spinning-jenny in England. When first he invented it the whole of the working men were against his invention, as they said it would take the bread out of their mouths. No sooner was it in work than the working men were increased by hundreds of thousands because they could produce more, and producing more they could make it cheaper, and by making it cheaper the consumers were doubled and trebled all over the country. Another instance of this is the case of all uncivilised races, or races where civilisation has stood still as in China. A few men only can live, and barely live, on a huge expanse of country if each subsists by the food he himself produces, but if on that same extent of country a number of men congregate and set up machinery and workshops, each becomes a specialist and supplies the whole community with an article which he and a few others alone produce, and the land supports more people than when each person supplied his own necessities.

III. If China becomes a manufacturing country she will undoubtedly hit individual British industries, but as long as the volume of our trade increases we need not fear. Our manufacturers in these individual industries will make money in fresh directions. Coventry is an example of what I mean. The destruction of the ribbon trade seemed to threaten Coventry with bankruptcy, but the

rise of the cycle industry has made the town ten times more prosperous.

I visited a great many mills in China, manufacturing both cotton and silk, and I went over many tea, sugar, and albumen manufactories. In every case I found that the mills under entire Chinese management were complete failures. Their system is to pay high dividends and put nothing aside for depreciation of machinery, and so the whole place goes to rack and ruin about the same time; and when the inevitable crash comes it practically means laying down completely new plant. I went to an intelligent mandarin at a cotton mill and I said, "Will you tell me what you pay in dividends?" He said, "32 per cent." I said, "How long have you been running?" He replied, "We have been running about three years." "What," I asked, "have you put by for repairs and maintenance?" He said, "We do not do that here." I said, "Will you let me have a look at your straps, shafting, bearings, and spindles?" He said, "Certainly"; and I showed him that some of the bearings were all gone, and that things were jumping about like a kangaroo. I told him the whole thing would not last very long, but he said he thought it would. The whole thing would soon go altogether, and they would have to put down a large new capital sum to start the whole plant again, simply because they do not do what the British engineer is so careful to do, namely, to look at the bearings, &c., every morning and see that all is correct. The silk industry is being killed by adhering to old-fashioned methods, and the Japanese, by introducing modern machinery, are competing to the disadvantage of China's silk trade.

The tea trade is declining for similar reasons, and it is almost entirely now in the hands of Russian merchants. They have a system of making brick-tea under hydraulic presses, and the latter I was pleased to see came from this country. I was also delighted to note in the several tea factories visited that the manager and director—what the Americans call the "boss" of the whole concern—was a Scotsman. However, it is Russian capital that starts it, and Russian dividends that are paid. This brick-tea is sent to Vladivostock and to the Black Sea. But there, again, I was glad to

perceive that it was sent in British ships. The Russians for a short time tried to use their own steamers to take their tea, but through some inability of the captains to manage these steamers the latter got aground, and ran into each other, and the profit account was not quite parallel with the loss account, so they fell back on the British vessels, which were running the tea cargo when I was there. Some remarkable facts were lately brought to my notice about the tea industry in India. The improvements which have been made from hand to machine manufacture, all of which is due to the mechanical engineer, have undoubtedly played a very great part in the steady advance in popular favour of Indian and Cingalese teas. The same process invented by mechanical engineers for cheapening and increasing the supply of tea in India and Ceylon was tried in China, but the Chinese would not part with the little plots of land they had. They would bring in their tea at different times, each man from his own little plot. It could not be made into a great tea garden, as in Assam and India; therefore the improvement which ought to have been made by the machinery was not brought about on this account. (There is another great difficulty connected with this industry, which I will refer to later on, as to the right of residence of Europeans in China.) The old hand-made process took up an enormous amount of room, required fifteen people to produce each 100 pounds of tea, and took a great deal of time. The introduction of British machinery by Mr. S. C. Davidson of Belfast, a Member of this Institution, who has led the van of improvement in tea machinery, has brought about a cleaner, more satisfactory, and more rapid mode of manufacture, which occupies a quarter of the time, and requires only one-fifth of the labour. Thirty years ago it was impossible to land tea in London under 1*s.* 6*d.* per pound. To-day the grower, by the aid of the machinery, can land and sell tea wholesale in London (at a profit to himself) at the price of 8*d.* per pound. I think it only right to direct the attention of mechanical engineers to the important questions of the manufacture of silk and tea, as I believe that British companies, established in China at treaty ports on British concessions or settlements, could buy up from the small Chinese farmers large supplies of raw silk and green

tea, and by improved methods of manufacture and modern machinery produce, in each of these industries, a superior article which would find a very ready sale.

I have dealt so fully in my book and in recent speeches with the machinery of the Chinese arsenals and the wonderful work turned out, that I will only allude to it very briefly here, and refer you to "The Break-up of China" for fuller details. I should like, however, to tell you one or two stories thoroughly characteristic of the Chinese. At Shanghai, in the superb arsenal under the superintendence of Mr. Thomas Bunt, who is a Member of this Institution, and Mr. Cornish, who came from the great works of Lord Armstrong in the North, I saw a gun which had had the breech-piece repaired in a most clever manner. It was a Krupp gun, with an Armstrong breech-piece fitted to it. I said to Mr. Bunt, "That is a very curious thing: how does a Krupp gun have an Armstrong breech-piece?" He replied, "They blew the breech-piece off." I said, "Did they?" and I went away. I went to a fort up the river where there is a clever mandarin, one of the most clever I met. I said to him, "Your guns are the only guns which appear to me to be mounted in a proper position for doing what you want them to do, which is to offer the enemy a proper front. Would you let me see the powder you use?" "Oh, certainly," he said. He sent for the powder, and after examining it I said, "You do not use that powder in these heavy guns?" He said, "Yes, we do." I said, "Why, if you use that powder you will blow the breech off, there is no give and take in a modern breech-loader fitted with a gas check—it is not like an old muzzle-loading gun—you will blow the breech off." He smiled, and said, "Yes, it does!" So I asked for further explanation, and he said he had loaded one of the guns—and remember these are 67-ton guns—and he had used this powder, and had blown the breech off, killing fourteen men. So I said, "But don't you cease using this powder? It is not suitable powder, it is far too quick in its action." "Oh, no," he said; "we loaded another gun with the same powder, and, would you believe it, the breech was blown off that gun too, and we killed twenty-four men." I was very much astonished at this, and asked him if he sent the guns to the Shanghai Arsenal. I had seen

there two guns which had performed that extraordinary manœuvre through the character of this powder. These guns must have cost the Chinese for their mounting, ammunition, etc., at least £50,000 apiece to get them out and mount them there.

Then I went to another place, where there was a battery of five 60-ton muzzle-loading guns, and I asked the mandarin where his front was—what his battery was put there for. He pointed in one direction, and I said, "Your battery's front is in the other direction." He said "Yes; I think there has been some mistake." I said, "Only one gun in your battery will bear, that is your right gun. If the enemy comes up the river that is where you ought to have had the front of your battery." "Oh, no," he said, "we should fire all the guns." I said, "Have you ever tried it?" He said "No, but we would when the enemy comes up." I said, "Would you mind trying it now?" And he was quite willing. I asked him to allow me to arrange the men, and he said I could do what I liked. I trained all the guns on the right, which was in echelon, but the wave of concussion from each gun would have killed every man at the gun in front, because the face of the piece was in the rear of the gun in front. I got the mandarin to allow me to put some soldiers' clothes and hats on the different guns. I commenced with the left gun and fired it, and the hats and clothes were blown to pieces. I did the same thing right along all the guns, but all the remark he made was, "Yes, it might kill some men, but the shot would hit the enemy."

Then I went to another place of the same sort, very close to this battery, where I noticed muzzle-loading 60-ton guns loaded absolutely in the magazine. The guns had to be run in, depressed at an angle of 45°, and then the rammer, which was worked by a winch, and sponge, sponged the gun, the powder came up, was put in the gun, and rammed home with the sponge. I said to the mandarin, "I have never seen anything so dangerous as that. If you had a careless No. 4 sponging the gun who did not sponge it properly, and put the powder in on the top of a lighted wad, you would blow up the magazine." The mandarin gave me a slap on the back, and said, "You are one of the wisest men I have ever met.

The year before last we did fire this gun and we blew up the magazine, and I will show you where it happened." He took me to the place where the magazine had blown up, and where he had replaced it in exactly the same condition. I asked him how many men were killed, and he said he did not quite remember, but he thought it was fifty.

One more story if I do not weary you. I am trying to prove to you how necessary it is to have a few British mechanical engineers out in China. I went to a powder mill, where they were making powder of the most approved pattern, what we should call pebble powder. I went in and I said to the mandarin, " You have got too much powder under that wheel "—he had a 2-ton wheel going round by machinery—very beautiful German machinery—" You have too much powder in the trough, and worse than that, you have all your windows open and all gratings open, and if you have a little dust blown in here you will make friction and all be blown up." The mandarin shut one eye, and said, " Yes, it does." He said, " It blew up last year, and this is the new place we have built in place of it."

However, please do not misunderstand me. These men are excellent men if they have a good man over them. They will copy everything, and there is no better mechanical workman in the world than the Chinaman, if he has a good foreman over him, and he is shown what he has to do by careful superintendence.

There is another thing which perhaps may amuse you. I went to one of the arsenals in the West, and the Chinese were extremely civil to me. They showed me everything, and they asked my advice, and I told them honestly what I thought. Of course I have not published a good many of their weak points, as it would not be chivalrous or right of me to do so. They trusted me with everything, they showed me all their machinery, arsenals, ammunition, and every kind of thing, and asked my advice. In one place I went into an arsenal where there was no European supervision, and I found a man boring a 6-pounder gun. He was an individual who evidently did not understand the speed and feed-gearing of his machine, because the gun was jumping about and making a discordant noise on the cutting-edge of the tool. I asked if I might adjust it for him, and I

took off my coat and adjusted the speed and feed-gearing as well as the cutter. It then went very well, and the shaving came out quite clean and without jumping. I saw the men all collected together after this, and I asked the mandarin what they were saying. They were saying, he said, that the English produced the most wonderful mandarins. He said, "We have many mandarins here, but there is not a single one of them that understands one bit about the machinery in the shop." The Chinese asked me to inspect their machines at other arsenals, where they had no European superintendent, and I showed them how to set their speed and feed-gearing for their steam tools.

In referring to the openings for mechanical engineers in China, in assisting to establish manufactories with modern machinery, and under European supervision and direction, the native wage is of course an important point to be considered. I found that in South China the current rate of wages for common coolies was 40 cents (9*d.*) per day; fitters 75 cents (1*s.* 5*d.*) to $1.25 (2*s.* 4*d.*) a day; smiths get 60 cents (1*s.* 2*d.*) to $1.50 (2*s.* 10*d.*) a day; carpenters 50 cents (11½*d.*) to 80 cents (1*s.* 6*d.*) a day; masons 60 cents (1*s.* 2*d.*) a day, and mill and refining hands 30 cents or 7*d.* a day.

Another opening for the mechanical engineer is to establish himself as an agent for British machinery in the foreign settlements and concessions. Over and over again I saw British machinery with the name-plates removed and German and Belgian names substituted, or where the name of the British firm was stamped in, it had been covered over by German and Belgian name-plates. This was notably the case at the iron mines at Hanyang and at one of the arsenals, where I saw some of Whitworth's tools so treated. I pointed this out to a Chinese merchant, and he explained it by saying that the Chinese usually bought their machinery through local agents in preference to sending abroad for it. These agents he said were more often than not Germans or Belgians, who understood machinery. The advantages of buying locally from an agent were threefold. (1.) Quicker delivery, as the machinery was often in stock. (2.) No trouble about the rate of exchange increasing the cost after it was ordered. (3.) The local agent could be held responsible for defects,

and was available for repairs if anything went wrong. I think this is a very important point for engineering firms, and it offers an opening for young men who are good mechanical engineers to take up the sale of British machinery, and to push it in preference to that of other countries. That the British machinery is good, sound, and loyal to its work is proved, because throughout China British machinery is predominant. There is a good deal of German and some American, and what I saw of both, with very few exceptions, was first-rate machinery. But the British certainly held its own as far as the opinion of the natives went; they frequently told me that they would prefer to buy British machinery, whether they bought it through foreign agents or not.

In connection with this matter I wish to draw the attention of engineering firms in Great Britain to the immediate necessity of establishing an exhibition of British machinery in China with mechanical engineers to explain and show its capabilities. I think a very great deal of this, and I hope you will too. The Chinese are a very practical race, and if they see what machinery can do they will often buy it. Both the Americans and Germans are already taking steps to provide such exhibitions of their goods, and it will have a serious effect on the sale of British machinery if we allow them to forestall us.

There is one other point to which I should like to refer before leaving this subject, because although it concerns the manufacturer of goods more than the mechanical engineer, it also affects the latter, who would be benefited by any change in the state of things I am going to draw your attention to. I have said it many times, but it is very true, and it cannot be said too often, namely, that the Germans and the Americans find out what the people want, and they make what the people want. The British do not find out what the people want, but they make what they think the people ought to have, which I need not tell you is a very different thing. From various points which were brought to my notice I was satisfied that one of the reasons why the British manufacturer fails to supply what the Chinese really want, and is losing ground against American competition, is the fact that our machinery is so often old

and obsolete. The British manufacturer does not write off enough of his profits for depreciation of machinery, and he does not avail himself of the latest machinery. The United States is far ahead of us in this respect. Very likely I shall get very much criticised over this statement, as people may say, "What do you know about it?" Certainly I only know what I saw, I only know what I was told, and I do think that generally throughout the country, certainly in America, and Japan, and Germany, that the manufacturers do take more trouble to get the very latest machinery than we do in this country. I saw the most extraordinary case in the United States—I have seen many cases but this was the strangest. It is only a few weeks ago that I saw a wire-cable making machine in New York, which cost £1,800, on the scrap-heap, after being in use for only twelve months. It was put by because an improved machine had come in, and the manufacturers at once bought the improved machine. As to labour-saving machines, the Americans certainly are ahead of us. I asked one or two of the biggest manufacturers why it was, and they said, "For two reasons, one is that we have not the amount of workmen that you have in England, and the other is that we always try to invent something to combat strikes." There is no doubt that a very large number of labour-saving machines in this country have been invented on account of strikes. I am not quite sure, but I believe the Linotype was an instance. In Great Britain one man controls one block for wire-pulling machinery, whereas in the United States one man controls four blocks. The United States workmen get higher wages, but their food, clothing, and rent are proportionately dearer. In Pittsburg eleven to fourteen kegs of nails are turned out by one man in a day, and the man gets 8*s.* a day wages. In this country only six kegs of nails are produced for 6*s.* a day. I am rather inclined to think, with great respect, that it is a popular error to think that wages are cheaper in this country than in America. I do not think so, for the simple reason that though a man may get 8*s.* in America where he gets 6*s.* here, he is not a dearer man if his output is double. That is a point for the mechanical engineers and the traders of this country to think over. The output is what one must think of. Whether you pay him 12*s.*, £1, or £2 a day, if

his output exceeds in proportion that of other men, certainly you are not paying him lower wages than are paid to the other men. Improved machinery means a larger output for less cost, but it does not necessarily mean that the workmen suffer. On the contrary, the increased output and reduced cost of production so cheapens the article that the demand increases, and in the end more men are employed than before, and wages are also higher. If Great Britain is to retain her superiority in China as a trading nation there must be improvements at home which will give fresh openings to the mechanical engineer in Great Britain, and this is equally true of all branches of industry. I may say with regard to that question of supply and demand that it is rather exemplified by the tariff. If a country puts a high tariff on, the consumer cannot buy the article. The effect of a tariff is to raise the price to the consumer; it is not to raise the price to the man who sells the article, as he puts it on to the consumer, and if the consumer cannot buy the article the man who stocks it cannot sell it. If there is no tariff, and the goods are within the reach of the consumer either by cheapness or by their plentifulness, both sides benefit. It is a question of volume and prices. Here is an instance: there was a paper in this country which sold for 3*d.*, and I believe the gentleman who owned it had £16,000 a year. He reduced it to 1*d.*, and I believe he now gets £50,000 a year. That is a very good example of volume and prices; the price was reduced but the volume of the paper increased, and both the customer and the man who owned the paper were benefited.

In conclusion, and by far the most important point for the mechanical engineer, or one of the most important points to deal with in my humble opinion, is the question of learning Chinese. It sounds rather a large order, but I venture to invite the attention of this Institution to the immediate necessity of training young mechanical engineers to learn Chinese, which can only be properly done by establishing a school of mechanical engineers in Hong Kong. The official Chinese should be studied, as all well-educated Chinese learn this; but for practical purposes, and conversing with labourers, each man must become a specialist in the dialect of the province in which he proposes to work. Americans and Germans are both doing this.

Now I bring this forward because both the Americans and the Germans have set to work most diligently to get both young American and German mechanical engineers to learn Chinese. I know that many of the older gentlemen who have been trading in China for many years opposed me on this question, among them, as I may say, the biggest man in China, Mr. Tom Jackson, who is head of the Hong Kong and Shanghai Banking Corporation in China, a man who has the whole rate of exchange of the East in his hands. He opposed me very strongly, but being an Irishman I naturally opposed him. Having argued that he had done so well without it all these years, and had done so well with the Comprador, that is the Chinaman who is the go-between between the British and Chinese (and for every dollar you make your Comprador makes another), he said I must be wrong, and hoped I would not support my view. But I had something up my sleeve. I said, "Mr. Jackson, the Hong Kong and Shanghai Bank has lately effected a large number of loans to the amount of many millions of pounds." He said, "Yes." I said, "Those loans were effected by means of your man, Mr. Hillier, in Pekin, a great friend of mine." He said, "Yes." I said, "Mr. Hillier in Pekin is the best Chinese scholar in China, but he is not only the best Chinese scholar in China, but is intimately connected, and acquainted thoroughly with the whole affairs of your bank. He is a banker. He has those two qualifications: he is a banker who knows the bank, and he speaks Chinese. Now remove Mr. Hillier out of it, and get your ordinary interpreter in Chinese, and would you ever have got those loans with the same advantage to yourself or to the Chinese?" He confessed he would not, so that I think I won my case.

For the benefit of mechanical engineers who are prepared to earn their livelihood in China, and to assist in the opening up of the country which is now going on, I will summarise the points where I think there is the best prospect of immediate openings.

1. *Railways.*—For all work in connection with railways the advice of Mr. Kinder, the engineer-in-chief of the Chinese Imperial Railways, should be sought, and applications for employment should

be made to the various syndicates financed by the Hong Kong and Shanghai Bank, particulars of which can be obtained in my book.

2. *Mining Work* is being undertaken by the Pekin Syndicate, which is the most promising venture at present, and by Mr. Pritchard Morgan's Syndicate, which has obtained valuable concessions in the Yantse Valley. Both of these Syndicates are well supplied at present with civil engineers, but there will doubtless be many openings for mechanical engineers in the near future. Electrical and hydraulic engineers should look out for the prospects of employment by the municipalities in the European settlements, and by large firms.

3. *Advertisements* in the Anglo-Chinese newspapers in Tientsin, Shanghai, Hankow, and other places, should for the present be the best means of securing billets in China for mechanical engineers willing to enter the employment of British or Chinese manufacturing firms.

Finally, until there is better security for life and property, and right of residence in the interior is fully accorded, engineers should be chary of accepting even official Chinese engagements requiring them to permanently reside outside the European settlements, as it is hardly fair for men to go to places where Chinese law does not permit a foreigner to live, and then to complain that their consul, hundreds of miles away, does not protect them.

I have great hopes that the proposal I made in America and Japan, and continually in this country—that the four great trading countries, Great Britain, America, Germany, and Japan, should come to an understanding that the integrity of China should be kept, and that the open door, with opportunity for the trade of all nations, should be maintained—will be accepted.

My remarks were not so well received either by the Government or the people of this country as they were in Japan or America. In Japan the whole of the mercantile classes were heartily with the idea, and they were prepared to go to any length to carry it out. In all the great towns I passed through in America, they were kind

enough to ask me to address the Chambers of Commerce, which were composed of all the shrewdest and hard-headed business men. Though they sympathised with my views, they said they did not think the time had come to carry out my proposal, and they did not see how it was to be done. That is what they said in this country. Our Foreign Office said they did not see how it was to be done—but they never tried. But in America you will find, if you read the papers, that they have come round to the opinion. I am quite delighted with the letters that I get from prominent men in America daily, saying, "Your ideas have taken root, and we think we shall come to the British and ask them to come with us and Germany and Japan to keep the door open for the trade of all nations." In saying that, there is nothing whatever offensive to other nations. People say, "Why do we leave out France and Russia?" For the very common-sense business reason that they have got no trade with China. Why are we to ask them to come and help when they have no trade? The whole of the Russian trade in Manchuria last year was two cargoes of seaweed—that is no joke; it is absolutely true, for I went to the Custom House at Newchiang and saw it registered in Custom House reports. In Kwangsi and Kuantung, where the French want to have a sphere of influence, we have sixteen million pounds' worth of trade in the year. In Manchuria we have four million pounds' worth of trade in the year. Therefore it is to our interest to keep the door open in China. It is not a selfish policy, it is a policy enabling all nations to come in level with us, a fair field and no favour. Those countries which seek territory and do not want trade, naturally want territory, so that where they have a sphere of influence and domination they can put a tariff on. For the life of me I do not see, if this country agrees to a sphere of influence in China, how you are to dictate to other countries whether they are to put a tariff on or not in their own sphere. As long as the door is open as it is at present, and as I hope it will remain, all nations can trade on the same platform, and if things go on as they generally do, we shall not get the worst of it.

The potential possibilities of the Chinese Empire are enormous and scarcely to be calculated. To the enterprise, pluck, perseverance,

skill, and knowledge of British mechanical engineers I confidently look for assistance in realising the latent resources of that ancient empire, and in keeping the flag of Great Britain ever in the van, no matter in what direction progress is made.

Discussion.

The President said it was their invariable practice to record in their Proceedings a vote of thanks to gentlemen who made communications to the Institution. On that occasion they could do no more for Lord Charles Beresford than they did for every author of a Paper. But he could assure Lord Charles that the Institution would not readily forget the meeting of that night. It was an entirely new departure for them to invite a discussion on the address of a gentleman who was not an engineer. While Lord Charles disclaimed any idea of being reckoned as a mechanical engineer, he might undoubtedly claim to be a "mechanically-minded man." They all remembered a picture which appeared in "Vanity Fair" shortly after the return of "The Commercial Traveller" from China; it represented what that Chinese workman called "the most wonderful mandarin ever seen." After listening to such a combination of wit and humour, shrewd observation and kind suggestion, they would all be disposed to fall in with the remark of the mandarin to Lord Charles, that he was "one of the cleverest men in the world." The thing in this address which had the greatest charm for him was, that while Lord Charles Beresford had not hesitated to point out what he conceived to be the weak points in their harness, while he had not given unstinted praise to British action and British engineers, he had never hinted a suggestion that this country was behind, or was likely to fall behind in the race of competition, if proper action were taken. In many British publications dealing with international competition, which no doubt sold very well because of their sensational character, it seemed to be assumed that Great Britain

(The President.)

was "played out." Of course it was easy for a nation in the earlier stages of mechanical progress to make large advances in any direction in proportion to the total that had been done before. It was difficult when a country occupied the commanding position that Great Britain did, with its enormous interests in manufactures, shipping, and business of all kinds, to make advances on the same percentage scale as could be made by nations in the earlier stages of progress. Let them look, not at percentages, but at solid facts. He once travelled abroad with a man of large experience in affairs—not an Englishman, but a man occupying one of the highest financial positions in Europe. This man said to him, "When I hear of competition, and of England going downhill, I think of what proportion of the total trade of the world belongs to England, and then I think that Englishmen ought to be ashamed to be afraid." On the other hand—and that Lord Charles Beresford had brought out clearly—if they wanted to hold their own they must not be ashamed to learn whenever other nations could teach them. They had taught the world so much in the past that they were apt to think they need not learn from anybody. If that ever became the state of mind of British engineers and manufacturers, then they would necessarily go downhill. They had to learn wherever useful lessons could be learned, and they had to thank Lord Charles Beresford for giving to British engineers many useful hints as to possible advances.

He had one announcement to make. If any lady or gentleman present desired to ask any question in relation to this address, or to the Openings for Engineers in China, Lord Charles Beresford would be very happy to answer them.

Mr. G. J. Morrison thought he was perhaps justified in saying one or two words on this subject, as he had had an opportunity of learning a little about China. He went out there twenty-five years ago to make the first railway in that country. He made the railway, opened it, and worked it for a year, and then saw the Chinese tear it up. That was an experience that had happened to very few. Since then he had thought many times of coming home, but each time he

saw in front of him the Chinese Will-o'-the-wisp, which was still keeping him out there now, for he was going to leave England in a fortnight to return to China. Whilst he could testify that pretty well everything Lord Charles had said was true, including even those wonderful stories, he thought possibly his lordship had not told everything. There were some difficulties to be encountered by anybody who chose to go out to China. A young man might go out there—for even now there were opportunities for young mechanical engineers—and as the men who went out were, as a rule, not the richest people in the world, when he arrived he found himself in a much better position than he was in here: he had a personal servant, he could join a club, and keep a pony, and he could lay by a little for a rainy day. But as soon as he got a little bit older, and wished to branch out, he met the same difficulties that any of the older engineers with capital and experience would meet, if they tried to go there and introduce anything into such a place as China. It was a very common thing for people to say that the whole of the mandarins in China were corrupt. He did not believe that to be the case at all; but they were obstructive. Of course the people here must not generalise too much from one or two examples. They may have met the Chinese Minister to England—a man very well acquainted with Europe, with a very good knowledge of English. When one spoke to him, one could speak on the same platform, and could give one's own reason for disagreeing. If, again, a man went to China for a short time, he might meet Shêng, the director-general of railways, a man of great administrative ability, a man who has mastered the idea that there can be a bargain which is advantageous to both parties. Therefore if one tried to make arrangements with Shêng, although he might not agree with one in every detail, at all events he would be ready to make some sort of agreement which eventually might work out well. But after all these were exceptional men. Pekin was the place where everything of importance had to be settled at last. The big people were in Pekin, and they were conservative, or retrograde, or whatever you might like to call it, to a degree one could hardly understand here. Supposing promoters had to deal with one of these people;

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they would tell him they proposed to make a railway, and hoped to get an income of £500,000 a year. The mandarin would immediately say, "You are going to rob China of £500,000 a year." They would reply, "That is not so. When the railway is built the people are not required to pay rates and fares on the railway unless they like. If they pay a dollar to a railway, it is because they would rather do that than waste time by going by boat." He would then reply, "That is what I say: you are not only robbing people but you are robbing the boatmen." They would move their ground a little, and would say, "A large proportion of the money is spent in wages." That was perhaps the best argument to use, but it would not suffice. He would reply, "Well, you pay wages, but you pay wages to men you are taking away from agriculture, where they would be doing a great deal more good for this country. At all events the money you send abroad to pay dividends and buy material is robbery pure and simple." They would try to get round him by saying, "We shall, as a matter of fact, pay the money into the bank, which will lend that money to the merchants, and the merchants will use the money to buy silk and tea, which will go home, and to that extent will be improving the trade of the country." The mandarin would reply, "That is what I say: you steal the money in the first place, and then you use the money to buy silk and tea, and you take away the silk and tea which ought to be consumed in this country." It would not be difficult to deal with that man, if he did not believe what he was saying; but he did believe it. He was a patriotic Chinaman, and doing what he could for the good of his country, at all events according to his lights. The promoters finding that they could not do anything with argument, and that the business had to be got through somehow or other, would have to arrange it in some other way. That mandarin had been brought up under the impression that the natural course of events was for a mandarin to be appointed with a salary of £100 a year, where his expenses were thousands of pounds a year. He had to take fees; he did not call them bribes, nor look on them as bribes. It was a method of collecting money which no doubt lent itself to abuse. It cost the speaker twenty-five years of the best years of his life to find out the difficulty and inconvenience

of dealing with such people. The mandarin knew that he had to take fees, and the promoters knew that fees had to be paid; they therefore set to work to make the best arrangement they could to get what they wanted; the mandarin also set to work to make the arrangement as good as he could for his own side. The foreigner, being a foreigner, must be rich, and therefore was fair game, and would have to pay higher fees than a native would pay. The Chinaman also thought he must make the best terms he could for his native country. He did not understand the subject very well, and translated that into what was to him an absolute equivalent, namely, "I have got to make the arrangement so as to give the worst terms possible to the foreigner." He did not understand an arrangement that could be mutually beneficial. The worse the terms for the foreigner the better for China. Therefore he set to work to make the terms as hard to the promoters as possible, the result being that the better the scheme one had to put before the Chinese, and the more honest the mandarin one had to deal with, the more difficult it was to put the thing through. That was a very sad state of affairs, and it made China very far from being a tempting place for people to go to if they took the same view of it as the speaker. He was quite of the opinion of Lord Charles Beresford, that the country was a splendid one. There were great openings and great possibilities. He could not call himself a great traveller in China, but he had travelled thousands of miles through the country by himself, picking up information here and there. He had set about his travels originally looking out for possible main lines of railway, from Hankow to Canton, from Hankow to Pekin, and from Chinkiang to Pekin. He had travelled along the course of most of the railways now suggested, and he had seen a good deal of the mineral wealth of China. There was no doubt about its being a rich mineral country. He knew a little also of the mineral wealth of the United States, and had seen something of the mining districts in Colorado and Montana, and was inclined to think that the United States ought to take a higher stand than China. He did not think China was the one country of the world, but it was quite true it was a very rich mineral country, containing lots of gold, coal, iron, and copper. In

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the West they had magnificent native copper and copper ores of all descriptions. Therefore there was a great opening for mining, if the Chinese would allow it. The Chinese, as was well known, had made terms with the Pekin Syndicate, and seeing that the syndicate had the matter well in hand, and would in his opinion carry things through successfully, he still believed it had been a very hard matter to bring things to the position they were in just now. A speedy realisation of their hopes in the near future was hardly a thing for promoters as a rule to look forward to. He would be very sorry if anything he had said to-night would tend to have the effect of keeping back a sufficient number of mechanical engineers from going to China, but he had not the slightest fear of that. The pioneer was always with them, and China was not so far advanced but one might speak of the people who went there as pioneers. The number, who would be attracted because it was an unknown country, was to his mind sufficient. No doubt in time the mandarins would change their minds, and things would improve, and for a future generation there would be a very great opening, but spending a life making that opening was not a business to which people could look forward to with complacency, as it was a business in which people were going to grow grey without arriving at any satisfactory result. It was not a comforting thing to look back and become aware of having grown grey in such work, but it was still worse to look forward to such a prospect. He said it from the bottom of his heart, that he feared that for a large number of people who looked forward to China as being a grand place to go to, there was a considerable amount of disappointment in store. What Lord Charles Beresford had said about concessions for railways was, of course, absolutely correct, and he was happy to say that the company with which he was connected, the British and Chinese Corporation, seemed to be in a very good way, and he hoped that during the coming year the work might be commenced upon some of the very important railways for which they had concessions. As soon as the railways were commenced, of course there were locomotives to be made, and various other things to be manufactured, but he was under the impression that the people who stayed at home would get these orders sent to them. He could not

help saying what he had said, and he regretted having to some extent thrown cold water upon what his lordship had said to them, but he really stood up there before that meeting as an awful example of the man who went out to China in the hope of making a fortune.

Mr. G. A. Goodwin said that having lately travelled in Japan and China for about two years it had been very gratifying to hear the address Lord Charles Beresford had given them, because the remarks he had made were entirely the opinions he had himself formed when out in the East. His chief reason for speaking now was to support the idea about having a British Exhibition in China. It was a suggestion that had originally occurred to him about eighteen months ago, and he had written a letter to the "Daily Telegraph" on 13th June last year, wherein he advocated and suggested an exhibition in Shanghai, that city being the seat of commercial business of the Chinese Empire. He also suggested there should be a floating exhibition whereby the manufactures of this country could be taken from port to port, and some of them taken for illustration even into the interior and shown to the Chinese, who were eminently a people who must see a thing before they would buy it. If one tried to induce them to have this or that machine, it was most difficult to get them to appreciate it. They could not understand drawings or photographs or plans, all being new to them, and they would turn round in their bland way and say, "Can you bring one Shanghai to look-see?" He felt sure it would pay the manufacturers of this country to exhibit machinery, pumps, presses for extracting oil, and such-like machines, and if they would combine together and have an exhibition there, attended by a properly qualified mechanical engineer and assistants to work and explain everything, he would be willing and prepared to associate himself with the movement and actively co-operate in it, even to the extent of organising and putting the scheme into a working condition. After the letter he had sent to the "Daily Telegraph," and others sent to the engineering papers, he had received letters from residents in Shanghai, all desiring to be associated with the scheme and highly approving of it. He was sorry to say, however, that the movement had been a slow one, and

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nothing had as yet come of it. The Chinese, in his opinion, did not desire the best machinery. They would not go to the expense. As long as the machinery would do the work of the present, they would leave the future to take care of itself. He would like to confirm what Lord Charles Beresford had said about the English manufacturer not supplying what was asked for. He knew from experience that that was true. Very often, on writing home for estimates for his clients, he obtained tenders for articles *not* asked for, while very often the manufacturers here would even take upon themselves to know best what was wanted. Their experience was no doubt very valuable, and they knew what was a good thing, if it was worked by proper labour, but where Chinese and Eastern people had got to use it they must allow the people on the spot to know what was wanted and best suited. He would seriously say that if they wanted to increase the trade of this country in the Far East, and to hold it, they must supply what was wanted and asked for, and nothing else. The Germans did most of the engineering trade in China, but he was pleased to say that 50 or 60 per cent. of the material sent out was of English manufacture. It was an undoubted fact that the Germans were more prone to learn the Chinese language than the British were, and they even travelled through the interior to learn the language, ways, and customs, and were not above mixing with the Chinese after business hours with the view of promoting trade, which the British would not do. The British would hardly speak to a Chinaman after business hours. He knew a case where a Chinese mandarin came into an Englishman's office, and the latter asked him to take his hat off, but the Chinaman could not as a matter of etiquette do that, and rather than allow him to continue in the office, the Englishman made him stand outside the door; so how could one hope to increase trade when such treatment was meted out to clients. He would certainly not advise engineers to go to China on speculation. Whoever went out should get an appointment on this side from commerical houses or large industrial concerns, syndicates, or companies. Only recently a personal friend of his went out there with several introductions; he was an engineer who had considerable experience of railways in

Africa. He was there three months and came back, having found absolutely nothing to do. The gentleman who received him best was a Russian friend of the speaker, who had his letters of introduction and testimonials translated into Russian and sent up to Port Arthur, but all appointments had been made even there. One great and most important matter to be remembered was, that the Chinese attached very great importance to what they called the "chop," or what we understood as the trade-mark. When a machine or article got into the Chinese Empire, it was its "chop" or trade-mark that it got to be known by, and afterwards, provided it gave satisfaction, they would not have anything else but that particular "chop," and even if the new machine were a better one and cheaper they would say, "No, we savey (know) this 'chop,' no wanty have other." Therefore he wanted to urge that the English manufacturer should be the first in the field to establish his "chop," and the people who followed him would have very great difficulty in ousting him.

With reference to the tool steel used in China, natives would not pay more than about £10 to £12 per ton for it, so that it was obvious it was not a high quality. Mr. G. D. Churchward, who had been the chief locomotive engineer of the Imperial Chinese Railways in Tongshan, used to make tools out of old rails, and he himself had seen them in use and they certainly did good work. He told him he thought there must be something uncommon about the steel; it was very old, he did not know the composition, but when made into turning tools, drills, and chisels, it worked very well indeed.

Mr. Emerson Bainbridge, M.P., said that he would confine the few words he had to say to mentioning one or two points to which Lord Charles had scarcely referred, and which seemed to have had a very important bearing upon the question of the development of trade in China. He did not think Lord Charles had put quite before the meeting the difficulties there were in opening trade with that country. He had not much more authority to speak on this question than that of having been recently in that country, and of following in Lord Charles' wake, and of hearing when in China

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something of the arguments laid before him. It seemed to him that Mr. Morrison gave a very fair and proper postscript to the excellent address which Lord Charles Beresford had given, and he described some of the difficulties. Being a Scotsman himself, Mr. Morrison reminded him of the large number of Scotsmen he met in his tour round the world, especially in China. The race showed their influence and power everywhere, reminding him of the story of a Scotsman who was speaking to an Englishman so highly of everything that was Scottish that the Englishman said, "Well, Sandy, you will be saying next that Shakespeare was a Scotsman," and he answered, "Weel, and judging from the abeelity he displayed, it would be a varra natural conclusion." He found in the whole course of his tour prosperous Scotsmen at the head of affairs. Mr. Morrison, whilst he enumerated difficulties, did not suggest a remedy, and the remedy in his own mind was one he wished to submit to Lord Charles. The greatest missionary they could have in China or in any other new country was the locomotive, but the question was how to get the locomotive there and get the railways made. He did not think they would ever get that done properly unless this country, in conjunction with some of the other progressive commercial countries, stood as a guarantor in one form or another for the capital put into China or similar countries. He did not mean a guarantor in the ordinary manner in which guarantees were made, but a guarantor in a similar way in which this country guaranteed the China loans. If once that was done, there would be more security, and the Chinese would have the gratification they so much coveted, of having English capital over there to spend upon their works, borrowing such capital with the view of returning it afterwards. The second point was this. Lord Charles said, and very truly, that one of the most important modes of developing trade in China must be by increasing the buying power of the people. Now the buying power of the people, as far as his experience went, was severely restricted by a system which was so common in that country—well-known he was sure to Mr. Morrison, but not referred to by Lord Charles—that interior taxation known by the mysterious word "likin," a system which allowed the mandarins in the interior

to have small salaries but large remuneration, by placing taxes every few hundred miles on every article produced in the country. Taking silk as an illustration, he was told by a gentleman in Shanghai that it was a very common thing for the "likin" taxes to amount to quite as much as the real value of the silk. If that could be altered, if the same system of excellent management that Sir Robert Hart introduced into the maritime customs could be applied to the interior customs, the effect would be to give the poor producers, who were very badly paid, higher wages, and thus increase their buying power. He hoped Lord Charles Beresford would be able to give them his own impressions of the disheartening manner in which this tax affected the development of the trade in that country. His own belief was that wherever one found a large country that combined three things—the power to grow cereals, the existence of sanitary conditions, and the presence of minerals—that country was very well worth developing by English capital. All those advantages were in China, from north to south. It was a country which, as far as he could judge, had ten times the riches and the scope for development that Africa had, but the means of developing had yet to be worked out. The difficulties were very great, but if they had information, such as was supplied by the address that evening, and if the attention of Englishmen were called to the matter, it was certain that some satisfactory schemes would be evolved for developing trade in that country.

Lord Charles Beresford said he had to thank the critics of his Address most warmly for having brought out some very important points which had been omitted, first because the Paper would have been too long, and secondly, because he was afraid he had forgotten them. But they were very important points in connection with the Paper which the Members had been good enough to listen to. He, perhaps, did throw rather a rosy view on the possibilities for a mechanical engineer in the future in China, but he still held to his view, and he would tell his hearers why. He was speaking of the future, and the immediate future, and though he entirely agreed with his friend Mr. Morrison as to the difficulties of the past, he did not

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see the difficulties of the future, for the simple reason that China was going to be opened up and there was no power on earth that could prevent it. There were going to be railroads in China; the Chinese had guaranteed them, and they would be held to their guarantee. There was Russian, French and Belgian, as well as English capital invested in those railways, and therefore the greatest civiliser in the world, and the greatest effort that could be made for opening up the country in the direction of manufactures and for the mechanical engineers were about to play their part in the country. The railways were going to be made in that country, and it was going to be opened up, and he thought this answered the point that his friend Mr. Morrison had made. He had had countless difficulties in China, and to a gentleman like him it must be rather bitter now, after all his trouble, and all the places he had surveyed, that so little should have come of it. Mr. Morrison was a great friend of his in China, and he owed him a great deal of gratitude for giving him so much information. The country was still as conservative as it was a few years ago, but in the near future the case would be quite different, and he ventured to say that in the next five or six years the chance for mechanical engineers in China would be enormous, for that one simple reason. Mr. Morrison also made some remarks as to the honest mandarin. There were plenty of honest mandarins in China and honest men in the Government classes, but the system did not allow them to be what we called honest. That might sound an Irishism, but it was absolutely true. He would give them a case in point. Mr. Morrison knew the gentlemen very well. Take the Viceroy Liu, or the Viceroy Chang; one ruled over forty millions of people, and the other over about thirty-three millions of people. One would imagine that a man who ruled over such a large number of people, who had charge of life and death, who had absolute control of the number and appointment of troops, who had absolute control of the whole of the administration, would get some suitable salary. One received £250 a year and the other £135 a year. Well, naturally they had to help themselves. Mr. Morrison gave his opinion of the system; but those two men were absolutely honest men; they did not rob their people to pay themselves. They really only took from their people by means of

taxes what was necessary to keep up their establishment, their army, their police, etc. That the people were robbed by underlings was quite true, but when one began with a great viceroy who ruled over thirty-five millions and went down to the man who ruled over one coolie, and they were all employed in the same system, one could imagine it was not very good for a country. But that there were honest and patriotic mandarins in China he declared was a fact, and very many of them, if the system could be altered. As for the people, one could ask any banker or merchant in China, or anybody who had ever travelled in China, and one would be told that the word of a Chinaman, merchant or trader, was as good as his bond. One did not want documentary evidence to deal with the Chinese, and if one had employed him to deliver £50,000 worth of silk in three months' delivery, and if through likin or other causes he must lose, he would bring the silk as loyally as if he must gain. That he had heard from every banker and merchant, Russian, German, and French, as well as Englishmen. When one had the patriotic mandarin and the honest trader, if only the system could be altered there would be a great opening in China, and everything would develop. Now came the point Mr. Bainbridge brought out about the likin and the question of borrowing money. In the speaker's own proposal for the guarantee of those four Powers who traded with China, he would say to China, "Yes, we should undertake to put your police and army in order, we should undertake a Chinese army with European officers in the same way that the maritime customs were managed by European officers under Sir Robert Hart, exactly the same principle which had provided the only valuable asset in China at the present moment. In return we would guarantee the integrity of the Chinese Empire, keep you as you are, and prevent you from being broken up into European provinces. Then you would alter your likin and your system of taxation and payment." As he told their Viceroy Liu, "A man in your position ought to have one million or two millions a year, not for your pocket, but to manage your people, and if you were properly taxed you would have it." The Chinese were not overtaxed but badly taxed; it was a tax on energy and enterprise. A man put up a building, built a

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boat, put up a spinning-jenny, or anything of that sort, and the mandarin taxed him, because he argued he could not do that unless he was a rich man. The man was taxed more than he could afford, and that killed enterprise. He maintained that as the railways were being opened the Chinese would develop themselves through the influence of trade and commerce, and it would be perfectly possible for them to put things right by helping the Chinese to remain undivided. It was not by having spheres of influence, where there would be in their own case a British-Chinese army, but by having a Chinese army ruled over and helped by foreign officers exactly as the maritime customs were at this moment. That was the argument he held forth in answer to the most sensible criticisms that had been made on his Paper. As Mr. Morrison had said, it was not all so bright. He himself did not think it was, but he thought it might be very easily made so, and it would be made so if these railways were made. They were going to be made, and would open up China. Mr. Goodwin made some remarks as to the exhibition, with which he was very glad to hear he agreed; a mechanical exhibition which would show machinery working would be an immense benefit. If you showed a Chinaman an article he would very likely buy it, but he would not listen to descriptions or take notice of photographs, prints, or anything of that sort. He thought the idea of a floating exhibition was most valuable. If the manufacturers of this country were to put a little money in as a capital sum and start one, he believed it would return them tenfold in the course of ten years. In connection with the "chop," everybody who had been in China knew it was a good thing and a very valuable one for good machinery. If the Chinese got a good "chop" they would not change it. One could not get anything purchased without the "chop," which the Chinese knew. He was astonished to hear Mr. Goodwin speak about the tool steel, because it was a thing he had looked into. He thought there were some tools faced with steel but made of very rough stove-iron, and so on, but there was a very great deal of the best Sheffield and Newcastle tool steel in many of the arsenals of China. Some of the arsenals made their own tools. Mr. Bainbridge remarked on the difficulties of the future, but

Mr. Bainbridge would agree with him that the characteristic of their race was to face difficulties, and the more difficulties there were the more anxious were they to grapple with them. He did not say for one moment that there were not enormous difficulties in this problem of opening up China, but he went back to his one point, to meet the criticisms that had been so fairly given, that China would be in an altered position in the very near future. All the difficulties that Mr. Morrison had pointed out were absolutely true and had existed, but those difficulties would be solved by the railways, and in a few years' time there ought to be 6,000 miles of railways in China. Railways would open up trade, railways would open up manufactories, railways would kill the likin, because a man could not stop the railway. As he endeavoured to explain in his Paper, it was on the same principle as a tariff. If the tariff were put too high the consumer could not buy because the tax would fall upon him. It was the same with the likin. He still adhered to his idea that China would be opened very shortly, and that the people who should study the opportunities that must occur for the benefit of trade and commerce and their own individual profession were the mechanical engineers of this country.

The Institution of Mechanical Engineers.

PROCEEDINGS.

December 1899.

The December Meeting was held in the House of the Institution, St. James's Park, London, on Friday, 8th December 1899, at Eight o'clock p.m.; Sir William H. White, K.C.B., LL.D., D.Sc., F.R.S., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that, in accordance with the Rules of the Institution, the President, three Vice-Presidents, and five Members of Council, would retire at the ensuing Annual General Meeting; and the list of those retiring was as follows:—

PRESIDENT.

Sir William H. White, K.C.B., LL.D., D.Sc., F.R.S., London.

VICE-PRESIDENTS.

Edward P. Martin,	Dowlais.
A. Tannett Walker,	Leeds.
J. Hartley Wicksteed,	Leeds.

MEMBERS OF COUNCIL.

Henry Chapman,	London.
Henry Lea,	Birmingham.
John G. Mair-Rumley,	London.
Henry D. Marshall,	Gainsborough.
John I. Thornycroft, F.R.S.,	London.

All of the above had offered themselves for re-election.

The following Nominations had also been made by the Council for the election at the Annual General Meeting:—

Election as Member.	MEMBERS OF COUNCIL.	
1867.	Samuel R. Platt, ...	Oldham.
1887.	Henry A. Ivatt, ...	Doncaster.
1897.	Alfred Morcom, ...	Birmingham.

All of the above had consented to the Nomination.

The President reminded the Meeting that, according to the Rules of the Institution, any Member or Associate Member was now entitled to add to the list of candidates.

The following nomination was then made by Mr. Arthur H. Hernu, *Member*, and seconded by Mr. James P. Maginnis, *Member*:—

VICE-PRESIDENT.

1881. John A. F. Aspinall, ... Manchester.

The President announced that the foregoing names, subject to the consent of the one added,* would accordingly constitute the nomination list for the election of officers at the Annual General Meeting.

The following Paper was read and discussed:—

"A continuous Mean-Pressure Indicator for Steam-Engines"; by Professor William Ripper, *Member*, of Sheffield.

The Meeting terminated at Ten minutes to Ten o'clock. The attendance was 96 Members and 72 Visitors.

* Mr. Aspinall has signified his consent to the nomination as a Candidate for Vice-President.

A CONTINUOUS MEAN-PRESSURE INDICATOR FOR STEAM-ENGINES.

BY PROFESSOR WILLIAM RIPPER, *Member*, OF SHEFFIELD.

The instrument described in the present Paper was devised in the first instance for the purpose of measuring the mean effective pressure on the piston of engines running at high rotational speeds. For this purpose an arrangement was adopted to separate the driving or impulse pressures from the resistance or back pressures, and to divert these two separate effects into two separate pressure-gauges, so that one gauge might give a continuous reading of the mean effect of the driving pressures only, and the other the mean effect of the back pressures only; the difference between the two gauge readings being the net mean effect. It was afterwards found possible to use the same instrument for engines running at any speed, high or low.

Description of the Instrument; Short-stroke Type.—In the Proceedings of this Institution (1897, page 347), in connection with the discussion on Mr. Morcom's Paper on Quick Revolution Engines, a description of the earliest type of this instrument was given, but since that date it has been somewhat modified, valves with either an oscillating, Plate 144, or rotating motion, Plate 150, having been substituted for a reciprocating motion of the spindle of the valve.

Figs. 1, 2, and 3, Plate 141, illustrate to one-third full size the simplest type of the instrument. Figs. 6 and 7 show the same instrument attached to the cylinder of an engine. Fig. 2 shows the valve A in mid-position. The piston of the engine is then supposed to be at the top or bottom of its stroke. Fig. 4 shows the position of the valve, when the engine piston is at or about mid-position, and

passing from the top to the bottom of the stroke, the steam from the top side of the piston passing into the driving-pressure gauge, and the steam from the bottom side of the piston passing to the exhaust gauge. Fig. 5 shows the valve reversed, when the piston is travelling in the opposite direction. The driving steam again passes to the driving pressure gauge, and the exhaust steam to the exhaust-pressure gauge, as before. The valve has no lap on either the steam or exhaust edges, and the respective ports are open to both gauges for the full length of the stroke. The valve is moving at its maximum speed at the points of opening and closing—that is, at the beginning and end of the engine stroke.

Long-stroke Type.—In order to prevent loss of pressure through excessive length of the pipes which attach the instrument to the cylinder in long-stroke engines, separate valve-boxes C and D, Figs. 8 and 9, Plate 142, are substituted for the single instrument, Figs. 1, 2, and 3. These valve-boxes are placed as near as possible to each end of the cylinder, so that they may take the steam at once, without loss of pressure due to passing through pipes. The valve-boxes are connected by pipes E and F, as shown, and the valves are so constructed as to turn the driving steam into one gauge G, and the back-pressure into the other gauge H. The arrangement of the valves A and B is shown in the sectional view, Fig. 13, Plate 143. The engine piston is supposed to be at the top of the stroke. The valves A and B are moving in the direction of the arrows. The top valve is opening communication between the top of the piston and the driving-pressure gauge, through the centre of the valve, and down the pipe E to the gauge G, Fig. 9 ; while at the same moment the lower valve B has closed the steam communication between the lower end of the cylinder and the driving-pressure gauge. At the same time the top valve is just closing, while the bottom valve is just opening communication with the exhaust side of the piston and the exhaust pressure-gauge H. There is a partition in the valve separating the steam and exhaust sides of the valve.

Fig. 14 shows an isometric view of the valves with the ports cut therein, and Fig. 15 shows that, when the faces of both valves are

moving together in the direction of the arrows, the steam port of the valve A is opening to steam while the steam port of the valve B is closing; also that the exhaust port of valve A is closing while the exhaust port of valve B is opening. The valves oscillate about their axes, and are driven by an eccentric fixed on a counter shaft, the counter shaft itself being driven by a chain gear from the main engine shaft.

Figs. 10, 11, and 12, Plate 142, show the arrangement of the instrument with a rotating valve for high speeds. With this instrument no eccentric is required, the valve being driven by a chain wheel. The valve is hollow and has two openings or ports which are on opposite sides and at opposite ends of the valve. The ports are respectively open during a half revolution to steam and during the other half revolution to exhaust. The steam is admitted to the gauge by entering the port at one end of the valve, passing through the centre of the valve, and entering the gauge pipe through the port at the other side and end of the valve. Figs. 17, 18, and 19, Plate 144, show the attachment of the long-stroke type to a horizontal cylinder.

Time-Pressure Diagrams.—The first point to be observed is that the mean pressure obtained by this instrument is the mean pressure on a time base, and not the mean pressure on a distance base, as is given by the ordinary indicator diagram. If the piston of an engine moved at a uniform speed throughout the piston stroke, then the mean pressure on a time base would be the same as the mean pressure on a distance base; but since the speed of the piston is not uniform, the mean pressure per stroke on a distance base, and the mean pressure per stroke on a time base, are not necessarily the same.

The two kinds of diagrams are illustrated by the two methods of indicating shown in Fig. 16, Plate 143, where the indicator A is one of the ordinary type, whose drum is connected by a string to a moving part of the engine giving it a motion to and fro, which is an exact copy to a reduced scale of the motion of the piston; and the diagram thus obtained is a pressure diagram on a distance

base. Indicator B, on the other hand, differs from indicator A in having its drum connected to the engine by an endless cord, by means of which the drum is made to rotate uniformly and independently of the irregular motion of the piston. The diagram thus drawn on the uniformly rotating drum is a pressure diagram on a time base, because it gives the pressure during successive intervals of time, without regard to the space moved through by the piston in those intervals. But since work is measured by pressure × distance only, it is important, if the mean time-pressure reading given by the gauges is to be of practical value, that it should be very nearly the same as the mean distance-pressure, or otherwise that there should be a definite and known ratio between them, which may be used for converting the one into the other. In practice the actual difference is small, as will be shown below, but whatever the difference may be, provided the ratio between the two kinds of mean pressure is definitely known, it is easy to convert the one into the other directly by the use of a factor expressing the known ratio.

A difficulty here suggests itself that the conditions may be very variable in the same engine, and that different points of cut-off and compression would require different factors; but it is possible in practice to use an average factor, which may be applied through all ranges of power, in the same engine, to convert the mean time-pressure into the mean distance-pressure within very narrow limits of error. This may also be done without any calculation by an adjustment of the scale of the pressure gauge, as shown in Fig. 20, Plate 144.

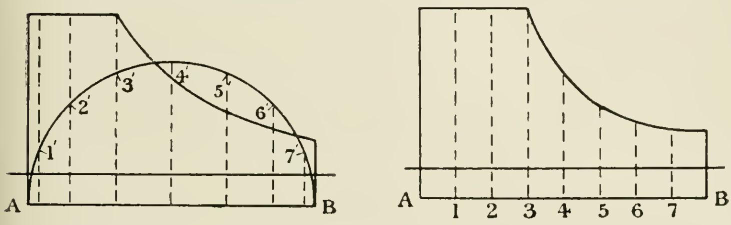
By the arrangement shown in Fig. 16, the diagram drawn on the drum of indicator B is shown in Fig. 22, Plate 145, and includes the forward pressure and the back pressure in one continuous line.

If an ordinary indicator be attached to the mean pressure instrument in the manner shown in Fig. 21, then it is possible by coupling the indicator to the driving-pressure nozzle to obtain, on one card, the forward or driving pressure lines taken together on one continuous roll, Fig. 23, or, again, by coupling the indicator to the back-pressure nozzle it is possible to obtain the backward or resisting pressure lines taken together on another continuous roll, Fig. 24. If a

dotted line be drawn through the mean height of the variable pressure line, as in Figs. 23 and 24, this dotted line will represent the mean effect of the series of variable pressures, Fig. 23 for the driving strokes, and Fig. 24 for the back pressure strokes. This mean effect is the reading given by the pressure gauges, which are respectively attached to the driving and back pressure sides of the instrument. The movement of the pointers of the gauges is reduced to a minimum by throttling. The higher the speed of the engine the more steady is the movement of the finger, other things being equal.

Fig. 25.

(*a*) Distance-Pressure Diagram. (*b*) Time-Pressure Diagram.



Relation between Time-Pressure and Distance-Pressure Diagrams.—The method of converting a distance-pressure diagram *a*, such as is taken with an ordinary indicator, into a time-pressure diagram *b* may here be explained. A semicircle is described on the base AB of the distance-pressure diagram, Fig. 25 *a*, and the semi-circumference is divided into any number of equal parts, 1′, 2′, 3′, etc. Also the base AB for the time-pressure diagram *b* is divided into the same number of equal parts. Draw at positions 1, 2, 3, etc., on *b* perpendiculars from the base line AB, in height equal to the height of the distance-pressure diagram *a* at positions 1′, 2′, 3′, etc., of the crank pin, and join the tops of these lines by a curve. Then this curve will give the forward-pressure line of the time-pressure diagram. A similar method is used for the back-pressure line. The same construction applies to the converse case of converting a time-pressure into a distance-pressure diagram.

(1) Taking first examples of simple theoretical diagrams, and considering the forward or driving pressures only, it will be clear

that if the steam is carried through the whole length of the stroke without expansion, then the two kinds of diagrams will in each case be a rectangle and their mean pressures will be the same. Figs. 26 to 33, Plate 146, are the upper lines of theoretical indicator diagrams for various points of cut-off. The expansions are assumed hyperbolic, with a clearance space of 7 per cent. The full line diagram is the true or distance-pressure diagram. The dotted line shows where the time pressure departs from the distance pressure. The shaded area represents the difference between the two. Table 1 shows a summary of the differences between the two diagrams for a series of cut-off points between 0·2 and the end of the stroke.

TABLE 1.

Point of Cut-off.	Percentage difference reckoned on the mean absolute forward pressure.
0·2	+ 2·9 per cent.
0·3	− 1·4 ,, ,,
0·4	− 3·5 ,, ,,
0·5	− 3·9 ,, ,,
0·6	− 3·4 ,, ,,
0·7	− 2·6 ,, ,,
0·8	− 2·1 ,, ,,
0·9	− 1·1 ,, ,,

Average percentage difference throughout the range from 0·2 to end of stroke = − 1·88 per cent.

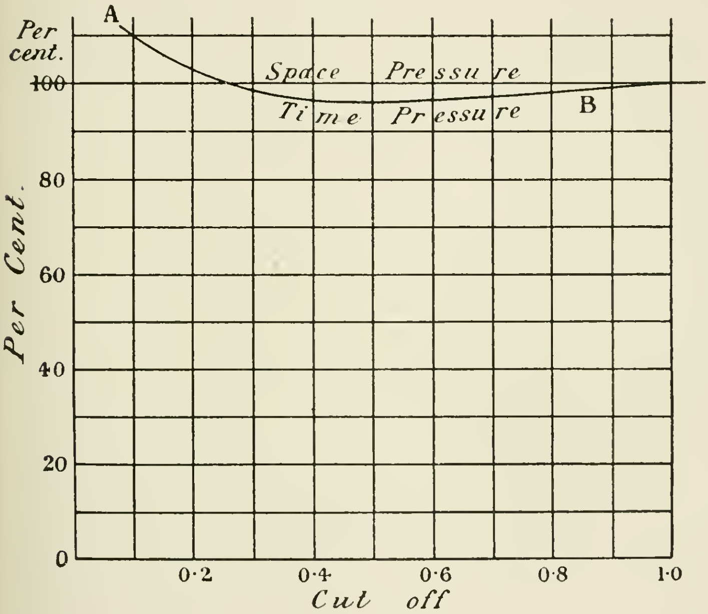
Fig. 34 (page 575) shows the same facts by means of the curve AB. The difference intercepted by the vertical between the 100 per cent. line and the curve AB through any point of cut-off on the base line represents the difference per cent., at that cut-off, between the two kinds of mean pressure for the forward or driving stroke of the piston. Figs. 35, 36, and 37, Plate 146, show further results under various conditions.

Fig. 38 shows that if the top line of the indicator diagram slopes uniformly from admission to release—which is the tendency, more or less, in high-speed engines—then the positive area which increases

the time-pressure diagram in the first half of the stroke is neutralised by the negative area in the latter half of the stroke and the two means are in this case equal to one another.

Considering the back-pressure line it will be seen from Figs. 39 to 42 that the compression corner introduces a more or less large difference between the time pressure and the distance pressure for the bottom line of the diagram, and that the larger the compression the

Fig. 34.

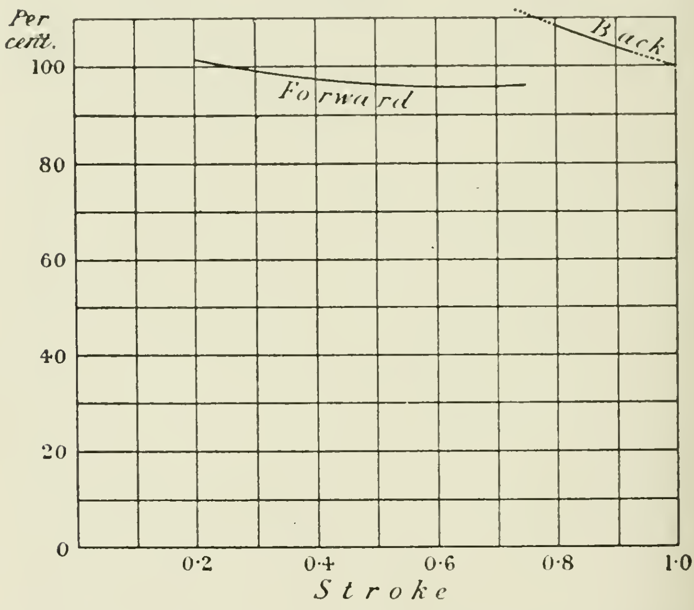


greater the difference between the two. The full lines of the Figs. 39 to 42 are the bottom lines of the diagrams as they would be taken by an ordinary indicator. The dotted curve is the time-pressure curve. The shaded area shows the difference between the two, and represents the amount by which the time pressure differs from the distance pressure.

Where a large compression occurs with an early cut-off, as in link motion engines, then both the upper and lower lines of the diagram show a high reading on a mean-pressure gauge, but being

both plus results the errors tend to neutralise each other, Figs. 43, 44, and 45, Plate 147. Fig. 43 is the indicator diagram when the valve gear is linked up to nearly mid-position. Fig. 44 is the top line of the diagram, and Fig. 45 is the bottom line. It is here seen that for this somewhat extreme case the error between the gauge reading and the true mean-pressure is the same in kind for both the top and bottom lines of the diagram, and that the net difference is − 1·86.

Fig. 50.



(2) Turning now from theoretical to actual diagrams the relation between the two kinds of diagrams taken from indicators A and B respectively, Fig. 16, Plate 143, was obtained over a full range of powers. Figs. 46, 47, and 48, Plate 147, are examples of those obtained by the ordinary indicator, and Fig. 49 represents a corresponding time-pressure diagram. The relation between the two is shown, Fig. 50 above, by means of curves as percentage of the true diagram. It will be seen that the forward-pressure line of the time-pressure

diagram is always a little low, averaging throughout the trials here given a difference of − 3 per cent. The back pressure is shown by the short line to the right of the figure and averaged 5·5 per cent. above the true back-pressure. The shaded areas marked 1 and 2, Fig. 49, distinguish between the compression area (1) and the lead area (2) on the back-pressure line of the diagram.

Trials of the Mean-Pressure Indicator.—For the purpose of determining the true ratio between the indicator and the mean-pressure instrument for any given engine or type of engine, if ordinary indicator diagrams be taken at varying loads, and the result be then compared with the reading by the gauges of a mean-pressure instrument, the relation between the two can be noted, and the average difference throughout the range of loads determined once for all. The extent of this difference in practice may be seen from the following series of trials made on the experimental engine at University College, Sheffield, Plate 148. The engine is of the marine type with compound cylinders 10 inches and 18 inches diameter, and 12 inches stroke, fitted with a link-motion valve-gear and a surface condenser. Average revolutions 100 per minute, boiler pressure 80 lbs. per square inch. The indicator diagrams, Figs. 46 to 48, Plate 147, are sample diagrams taken during the trials, and are numbered by letters to correspond with the letter number of the trial. The experiments were made on the high-pressure cylinder of the engine working under light, medium, and heavy loads, and under varying ranges of expansion, numbered, full steam, first grade, and second grade. The indicator diagrams were taken with Tabor indicators, the springs of which were tested before and after the trial and found correct. The pressure-gauge readings were measured by means of a Schäffer and Budenberg duplex standard test-gauge for the driving pressures, and by a specially standardised large dial-gauge for the back pressures.

From Table 2 it will be seen that the readings of the forward and backward pressure-gauges when compared with the indicator diagrams showed an average difference of − 3·1 per cent. for the

TABLE 2.

Successive Trials, taken 25th November 1898.

No. of Trial.	Forward. Reading by Forward Pressure Gauge. abs.	Forward. Mean Forward Pressure by Indicator. abs.	Forward. Difference.	Back. Reading by Back Pressure Gauge. abs.	Back. Mean Back Pressure by Indicator. abs.	Back. Difference.	M.E.P. Time.	M.E.P. Distance.	Difference.
				Block at the End of the Link.					
A	34·7	35·5	− 0·8	13·7	14·5	− 0·8	21·0	21·0	0
B	32·7	34·6	− 1·9	13·5	14·0	− 0·5	19·2	20·6	− 1·4
C	39·7	41·5	− 1·8	18·2	19·4	− 1·2	21·5	22·1	− 0·6
D	40·7	41·8	− 1·1	17·7	18·5	− 0·8	23·0	23·3	− 0·3
E	44·7	45·9	− 1·2	18·7	19·2	− 0·5	26·0	26·7	− 0·7
F	44·7	46·6	− 1·9	18·7	19·2	− 0·5	26·0	27·4	− 1·4
		Mean	− 1·5 or − 3·8%			− 0·7 or − 4·2 %			
				First Grade Expansion.					
G	39·8	42·6	− 2·8	21·1	22·2	− 1·1	18·7	20·4	− 1·7
H	40·2	41·9	− 1·7	21·5	22·2	− 0·7	18·7	19·7	− 1·0
J	46·0	47·6	− 1·6	23·7	23·5	+ 0·2	22·3	24·1	− 1·8
K	45·5	46·7	− 1·2	24·2	24·5	− 0·3	21·3	22·2	− 0·9
L	51·7	52·6	− 0·9	25·2	25·5	− 0·3	26·5	27·1	− 0·6
M	50·5	51·4	− 0·9	25·7	26·4	− 0·7	24·8	25·0	− 0·2
		Mean	− 1·5 or − 3·3%			− 0·5 or − 2·1%			
				Second Grade Expansion.					
N	50·2	52·0	− 1·8	35·2	33·8	+ 1·4	15·0	18·2	− 3·2
O	50·2	51·7	− 1·5	36·0	35·5	+ 0·5	14·2	16·2	− 2·0
P	53·7	54·3	− 0·6	36·2	35·1	+ 1·1	17·5	19·2	− 1·7
Q	54·7	55·7	− 1·0	37·0	36·1	+ 0·9	17·7	19·6	− 1·9
R	55·7	56·7	− 1·0	36·7	35·8	+ 0·9	19·0	20·9	− 1·9
S	55·2	56·3	− 1·1	37·7	37·6	+ 0·1	17·5	18·7	− 1·2
		Mean	− 1·2 or − 2·2%			+ 0·8 or + 2·2%			

Mean difference throughout the whole range forward = − 3·1 per cent.
Do. do. do. do. do. do. backward = − 1·4 do. do.
Net difference do. do. do. do. = − 1·7 do. do.

forward pressure, and of $-1 \cdot 4$ per cent. for the backward pressure or a net difference of $-1 \cdot 7$ per cent.

If it is desired to avoid the use of factors, the forward and backward pressure-gauges may be graduated as shown in Fig. 20, Plate 144, the scale being increased by the required per cent. of the absolute pressure. The true mean effective pressure may then be read direct from the gauges without any further correction by taking the difference between them to within a limit of error not greater than 1 per cent.

It is probable that this average percentage correction will vary for different types of engines, but experience with the instrument will determine the factor or gauge correction necessary for any given type.

Readings by Pressure Gauges.—In order to obtain a reading of the mean pressure acting upon the gauge, the writer employs two throttling cocks, one close to the instrument and one more or less close to the gauge. By the use of these regulating cocks the oscillations of the finger of the gauge may be reduced to any desired degree of steadiness without interfering with the accuracy of the reading of the mean pressure.

It is not unlikely that some engineers will object *ab initio* to the arrangement described in this Paper, seeing that it is proposed to obtain such an important value as the mean effective pressure in an engine cylinder by means of an appliance so unreliable as the pressure-gauge is said to be, by some authorities, and still more so when it is proposed to throttle the steam supply to the gauge, as has just been described.

But in answer to these objections the author desires to give the results of his own experience, as, having himself been in doubt as to the accuracy of gauges and the effect of throttling, he has made many hundreds of experiments in order to test the extent of the error to be expected, and he has come to the conclusion that readings by a pressure-gauge may be obtained which are as accurate, as consistent, and as reliable, as by any known instrument for the measurement of pressure, not excepting the best of indicators; also that the

throttling, when properly applied, does not endanger the accuracy of the reading, but on the contrary gives the true mean effect of the regular successions of momentary variations of pressures acting on the gauge.

In order to obtain accurate readings by means of a pressure-gauge, such gauge must (1) be properly constructed; (2) be properly used. That a large number of the pressure-gauges in ordinary use in practice are more or less unreliable is well known, but it will be admitted that such gauges, of the unreliable class, have not been constructed for the purpose of extremely accurate measurements, and have not received that care in the process of manufacture which is necessary to enable them to be classed as "instruments of precision." Their deficiencies are usually not due to defect in the principle upon which they are constructed, but are rather a question of quality of manufacture. But however perfectly constructed a gauge may be, it is of course necessary that it should be carefully used, if it is to be expected to give uniformly accurate readings. Probably no instrument used by engineers receives such scant attention as the pressure-gauge, and while some of our measuring instruments must be carefully cleaned, oiled, and set, before we may have a single measurement, the pressure-gauge may be dirty or rusty, or hot or cold, or its syphon may be empty or full, but under all these conditions it is expected to be equally accurate.

Pressure-Gauge Syphons. — The importance is admitted of maintaining a column of water in the syphon of the pressure-gauge to keep the gauge cool, so that its readings may be consistent, and so as not to subject the gauge to high or variable temperatures. It is generally supposed that if the gauge has a syphon there is always water in it, and that when the syphon is once full of water, the water is easily retained therein, but these assumptions are not warranted by the facts of the case. The water will disappear from the syphon from various causes: (1) If there is the smallest leak in the gauge end of the syphon; then the water is all gone in a minute or two by being blown out by the steam, though the leak may be almost imperceptible.

(2) If the pressure to which the gauge is subjected is a variable one, as is the case when the gauge is attached by its syphon to the valve chest of an engine regulated by a throttling governor; then the water will disappear from the syphon as usually constructed in a few minutes, especially on a sudden reduction of load, and consequent fall of pressure, in the same way that water in the engine cylinder disappears during expansion and exhaust. (3) When the gauge is liable to be subjected to a vacuum, as is the case when it is attached anywhere on the engine side of the throttle valve; then if the throttle valve is closed by the governor, or by hand, while the engine continues running, especially if it is a condensing engine, the engine becomes an air-pump and the water in the syphon is displaced by the expanding air initially contained in the spring tube of the gauge and its connections. Thus if the pressure in the engine falls to 3 lbs. absolute, the volume of water displaced in the syphon equals $15 \div 3 = 5$ times the volume of air in the gauge. If now the steam is again suddenly turned on the engine, it is certain that the gauge readings will be different from what they were when the syphons were full of water. When there is water in the syphon the syphon pipe is practically cold with a steady pressure. When the pipe is very hot the water has probably gone from the syphon, unless it happens that the pipe is in contact with some hot metal. (4) If the gauge is subjected to a vacuum, and there is the smallest leak in the fittings at the gauge end of the syphon; then the water in the syphon is displaced by the air which enters the syphon through the leak.

To Prevent the Disappearance of Water from the Syphon.—(1) When the cause is due to the variable nature of the pressure acting on the gauge the water may be retained in the syphon by the method of double throttling already mentioned. When the mean-pressure instrument was first constructed, only a single cock was fitted to the syphon of each pressure-gauge,* and great difficulty was found to keep the water in the syphon. Many devices were tried to overcome this difficulty

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* See Proceedings 1897, page 347, and Plate 76.

but without avail. A second cock would have been fitted at an early period of the experiments, at the end of the syphon farthest from the gauge—which, when throttled, would instantly have stopped the trouble—but for the fact that the writer set out with the notion that if the throttling of the syphon cock was a throttling of water the pressure would be transmitted to the gauge undiminished, but that if the throttling took place in the steam a loss of pressure would follow, and the reading of the gauge would be low. This erroneous notion cost about twelve months' experimenting to try to discover how to do without the use of water in a syphon.

One of the devices tried by the writer to overcome the difficulty may be of interest. A differential pressure-gauge was constructed, as shown in Fig. 52, Plate 149. The driving pressure steam was admitted from the mean-pressure indicator valve-box A by the pipe B against the piston C. The back pressure was admitted by the pipe D against the piston E. The pistons C and E were attached to the same rod which was made an easy fit to prevent friction as far as possible, and the movement of the piston was regulated by the indicator spring F. To prevent violent motion of the pistons a dash-pot G was added which was filled with oil, and its piston was also made to work quite smoothly. Holes were made beyond the pistons C and E to allow of the free escape of any steam which might pass the pistons. The method of transferring the movement of the pistons to the finger of the gauge will be understood from Fig. 52. This instrument was not satisfactory, as it was not sufficiently sensitive, and a further attempt was made to improve the action of the water syphon.

Fig. 53 shows the arrangement employed for experimenting on the effect of double throttling. A short water-gauge glass A is secured between two plates B and C held together by bolts. The glass is connected at the top with the engine cylinder D by the pipe as shown, and at the bottom of the glass the gauge-pipe is attached. There are regulating cocks at E and F. When the cock E is opened wide and the engine is running, the change of pressure in the cylinder between the driving and the exhaust stroke caused a more or less violent agitation of the water in A, being the more violent as the range of pressure was greater. When the range of pressure was not

more than about 10 lbs. the water in the glass was quiet, but when the range of pressure exceeded this (by increasing the load on the engine) agitation again began. The action appeared to be due first to the heating of the water in the tube by the rush of steam, mixed with globules of hot water, into the tube; and secondly, to the re-evaporation of the heated water when the pressure fell during expansion and exhaust in the cylinder. It is not possible to give numerical data as to the effect of different ranges of pressure because the behaviour of the water was most erratic. Sometimes with a given range of pressure in the engine, the water was violently agitated and would disappear from the glass in a few minutes; in other cases it would remain quiescent in the glass for hours, though the conditions appeared to be unchanged. Then it would suddenly commence to boil and to disappear without any apparent cause. But in all cases of agitation of the water in the tube A, when the cock E was throttled down the agitation immediately ceased.

The amount of throttling of the cock E which was necessary to stop the agitation still left a fairly large movement of the gauge finger across the scale, and the final adjustment for steadying the finger to the smallest possible movement was obtained by throttling the cock F. Throttling the cock E had no effect on the pressure reading by the gauge unless the throttling was carried too far. It was not necessary in order to stop the ebullition to throttle the cock E so far as to reduce the pressure. If any doubt remained as to whether the cock E was throttled too much, a little more opening of E would show at once whether such was the case. But it is only necessary to move E sufficiently to stop the ebullition and consequent disappearance of the water, and this leaves a good margin before the throttling of E is excessive.

With such an arrangement the effect of suitably throttling the cock E is to automatically fill up the syphon, if partly empty from any cause, and the water in the syphon will thus reach as far as the cock E when the apparatus has been at work a short time. In this way the problem of keeping the water in the syphon continuously and free from agitation was solved, and there is now practically no difficulty in obtaining a constant and accurate reading of the mean pressure by gauges subjected to variable pressures.

(2) When the cause of loss of water in the syphon is due to the gauge being subjected to a vacuum, a type of gauge is preferable from which the air in the Bourdon tube has been excluded, and the tube filled with liquid to its extremity; there is then no air to expand in the tube to expel the water from the syphon.

To sum up:—(1) The instrument here described gives a correct record of the mean time-pressure. (2) The mean time-pressure bears a definite ratio to the mean pressure as given by an ordinary indicator. (3) The correction may be made by the use of a factor, or by a corrected scale on the gauge dial. (4) Pressure-gauges when properly made and properly used may be relied upon to give accurate readings.

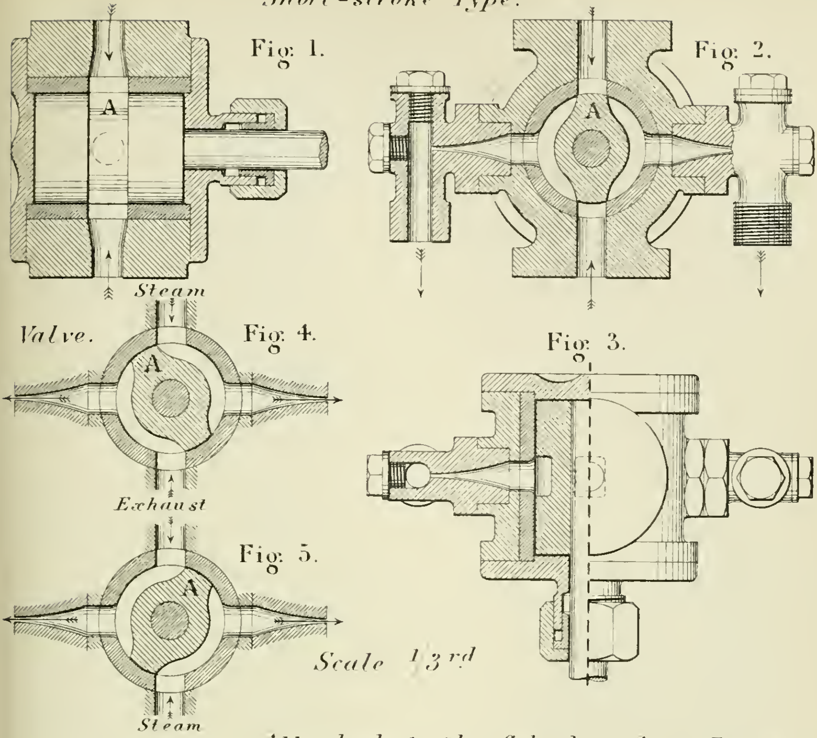
In conclusion, the author wishes to acknowledge his indebtedness to his assistant Mr. J. W. Kershaw, M.Sc., who has rendered considerable help in carrying out the experiments.

Discussion.

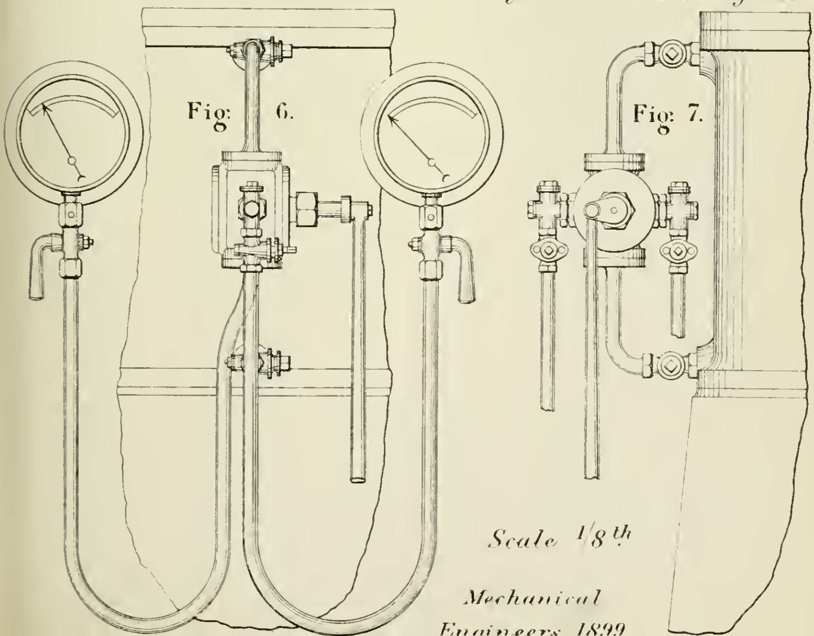
The PRESIDENT said the proceedings were not quite of the same character as those of the last meeting, when the members had listened to some very racy stories and interesting suggestions; but he thought that from the professional side the discussion, following upon Professor Ripper's excellent Paper, was likely to be of great benefit to mechanical engineers and users of steam. Those who had seen the work which Professor Ripper was doing in the University College at Sheffield would realise what an advantage it was when a gentleman, who had been thoroughly trained as a practical engineer became a teacher of the theory of steam and of engineering generally. In the name of the Institution he tendered to Professor Ripper its best thanks for his excellent Paper.

MEAN-PRESSURE INDICATOR. *Plate 141.*

Short-stroke Type.



Attached to the Cylinder of an Engine.



Mechanical Engineers 1899

MEAN-PRESSURE INDICATOR.

Attachment to Vertical Cylinder.
Long-stroke Type.

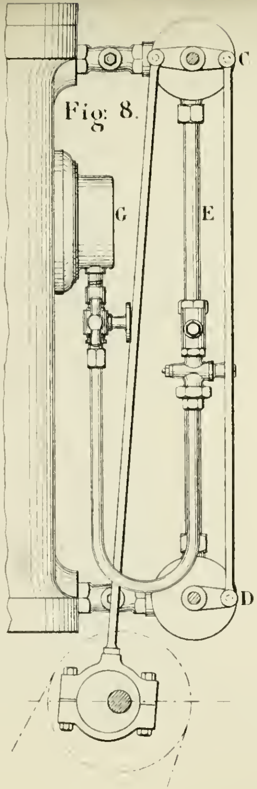


Fig: 8.

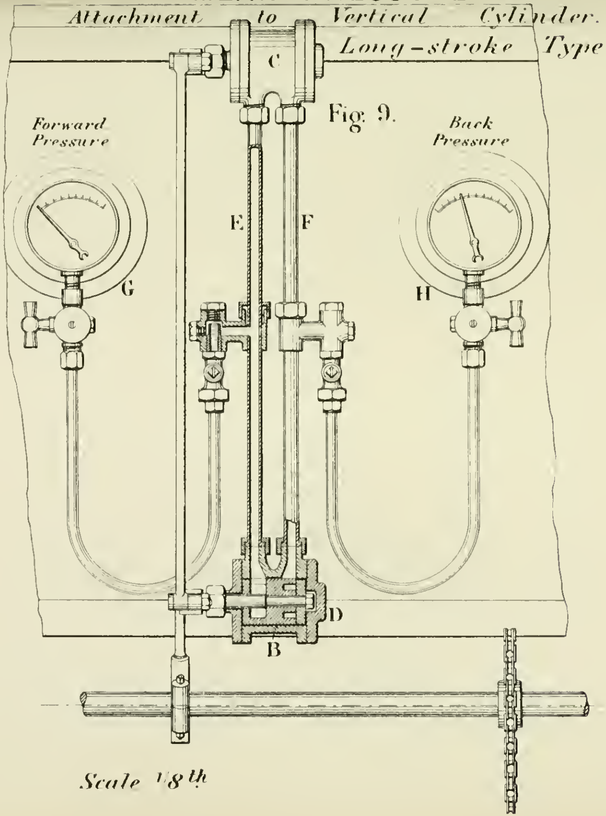


Fig: 9.

Scale 1/8th.

Rotating Valve for High Speeds.

Fig: 10.

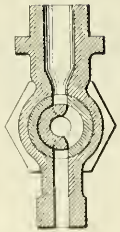


Fig: 11.

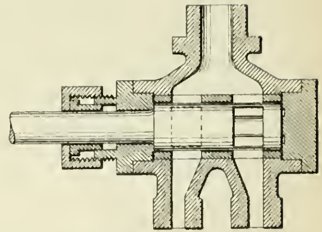
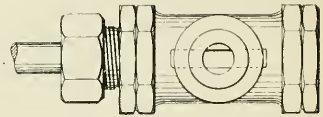


Fig: 12.



Scale 1/3rd.

Mechanical Engineers 1899.

Plate 142.

MEAN-PRESSURE INDICATOR.

Valve for Long-stroke Type.

Fig. 13.

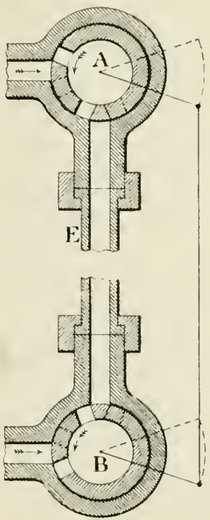
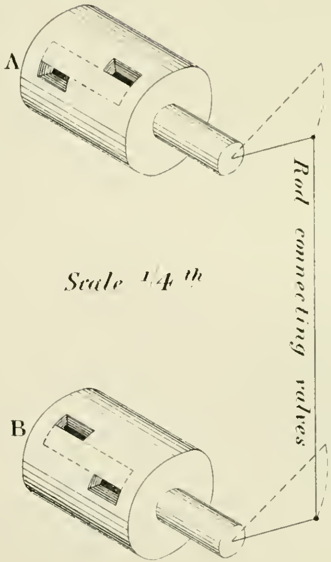


Fig. 14.



Scale 1/4th

Fig. 15.

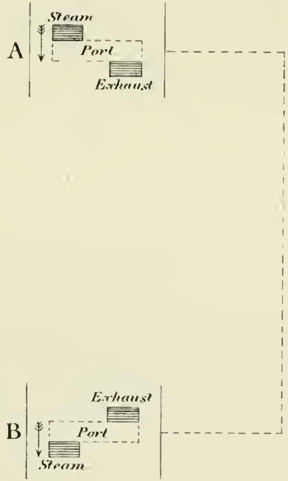
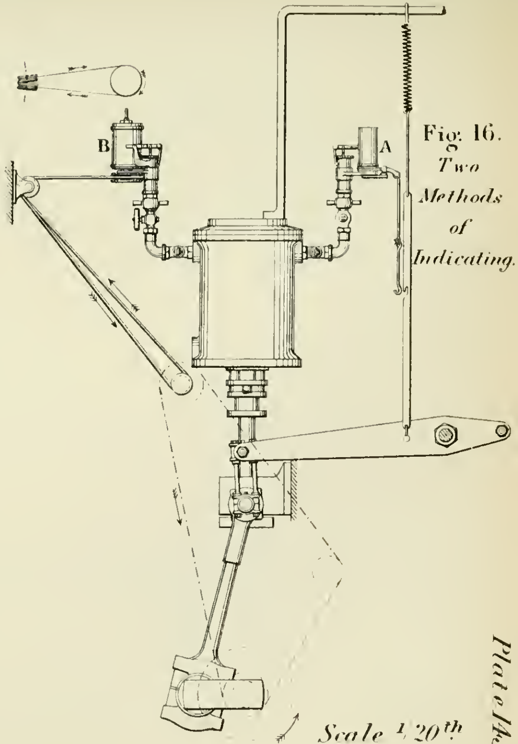


Fig. 16. *Two Methods of Indicating.*



Scale 1/20th

Plate 143.

MEAN-PRESSURE INDICATOR.

Attachment to Horizontal Cylinder.

Long-stroke Type.

Fig: 17.

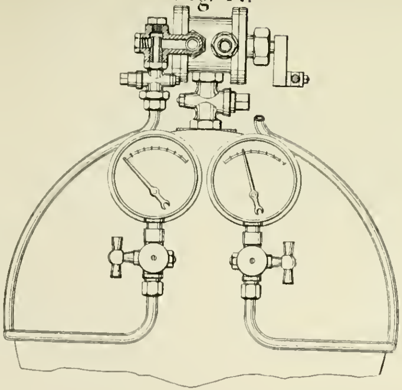


Fig: 18.

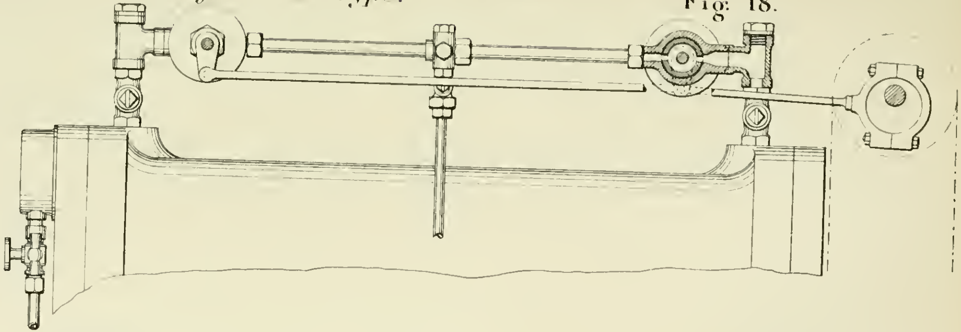
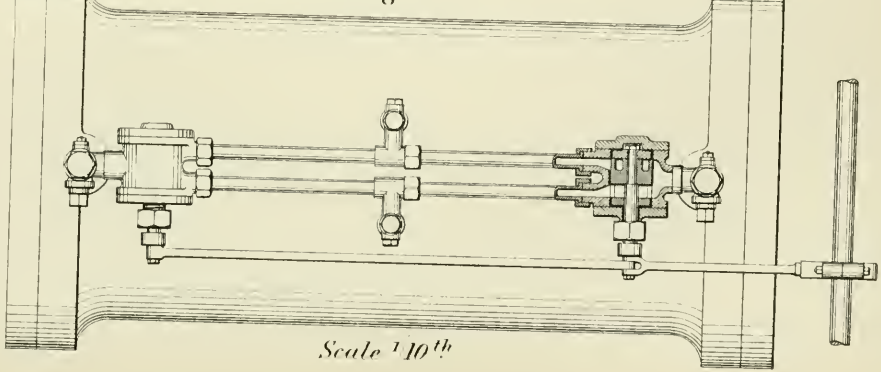


Fig: 19.



Scale 1/10th

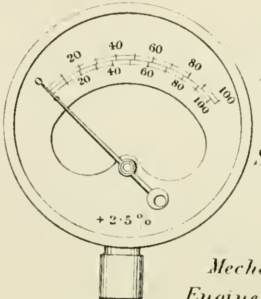


Fig: 20.

Pressure Gauge.

Scale 1/5th

Mechanical Engineers 1899.

Plate 144

MEAN - PRESSURE INDICATOR.

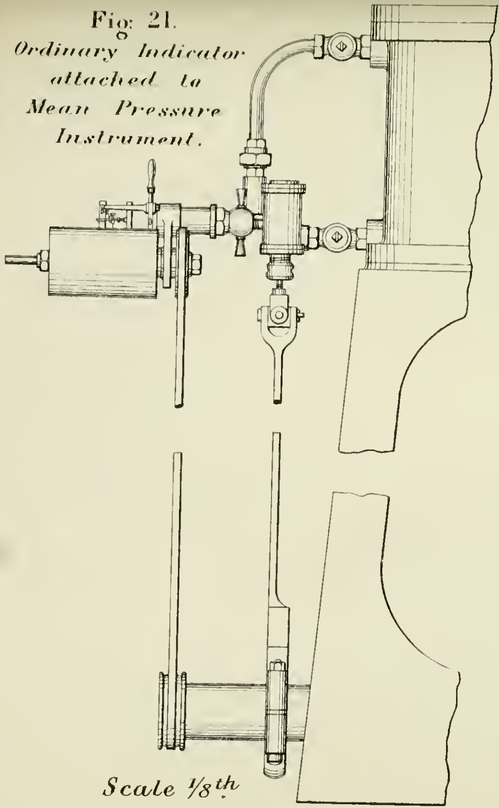


Fig: 21.
Ordinary Indicator attached to Mean Pressure Instrument.

Scale 1/8th.

Fig: 22. Forward and Back Pressure (not separated).

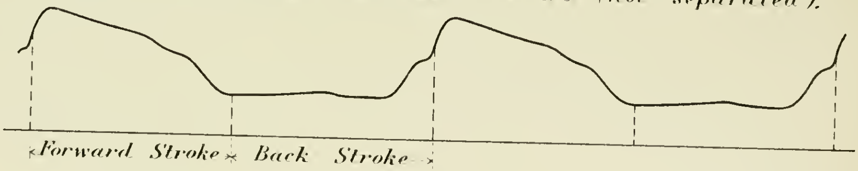
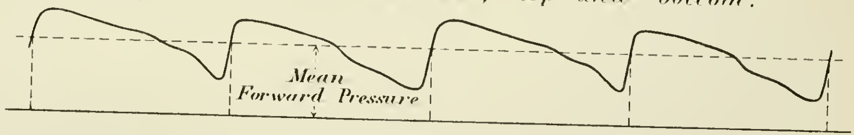
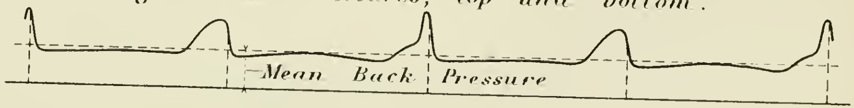


Fig: 23. Forward Pressures, top and bottom.



Scale 1/108th.

Fig: 24. Back Pressures, top and bottom.



Mechanical Engineers 1899.

Plate 145.

MEAN - PRESSURE INDICATOR.

Theoretical Diagrams showing the relation between Time-Pressure and Distance-Pressure.

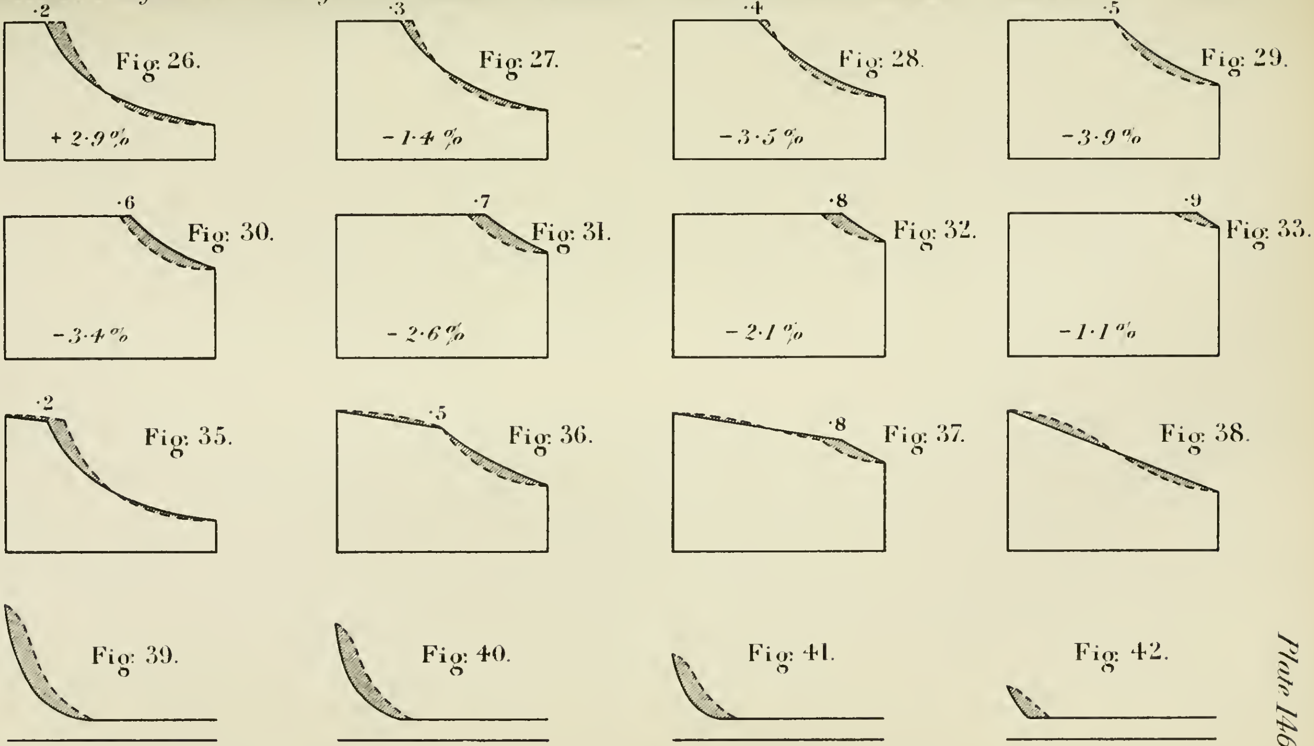


Fig: 26. Fig: 27. Fig: 28. Fig: 29.

Fig: 30. Fig: 31. Fig: 32. Fig: 33.

Fig: 35. Fig: 36. Fig: 37. Fig: 38.

Fig: 39. Fig: 40. Fig: 41. Fig: 42.

Plate 146.

MEAN-PRESSURE INDICATOR.

Relation between Time-Pressure and Distance-Pressure.

Fig: 43.

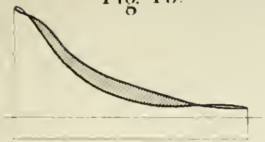
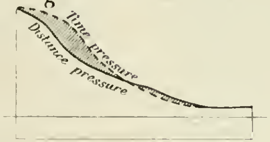
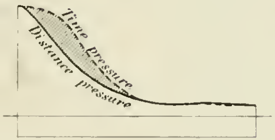


Fig: 44. *Forward Pressure.*



Mean Forward Distance-Pressure = 44·04 *abs.*
" " *Time* " = 47·16 *abs.*
+ 3·12 *lbs.*

Fig: 45. *Back Pressure.*



Mean Back Distance-Pressure = 37·5 *abs.*
" " *Time* " = 42·48 *abs.*
+ 4·98 *lbs.*

Mean-Effective Distance-Pressure = 6·54
" " *Time* " = 4·68
Net Difference = −1·86 *lbs.*

Fig: 46. *Trial* F, *Table* 2.

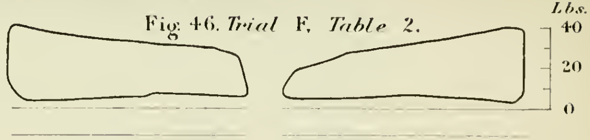


Fig: 47. *Trial* L.

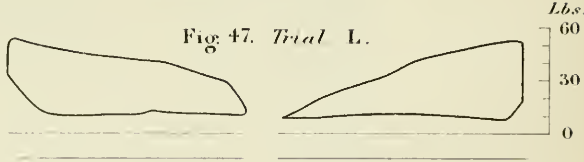


Fig: 48. *Trial* R.

Fig: 49. *Time-Pressure Diagram.*

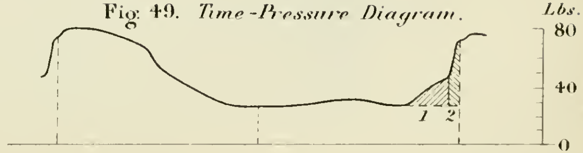
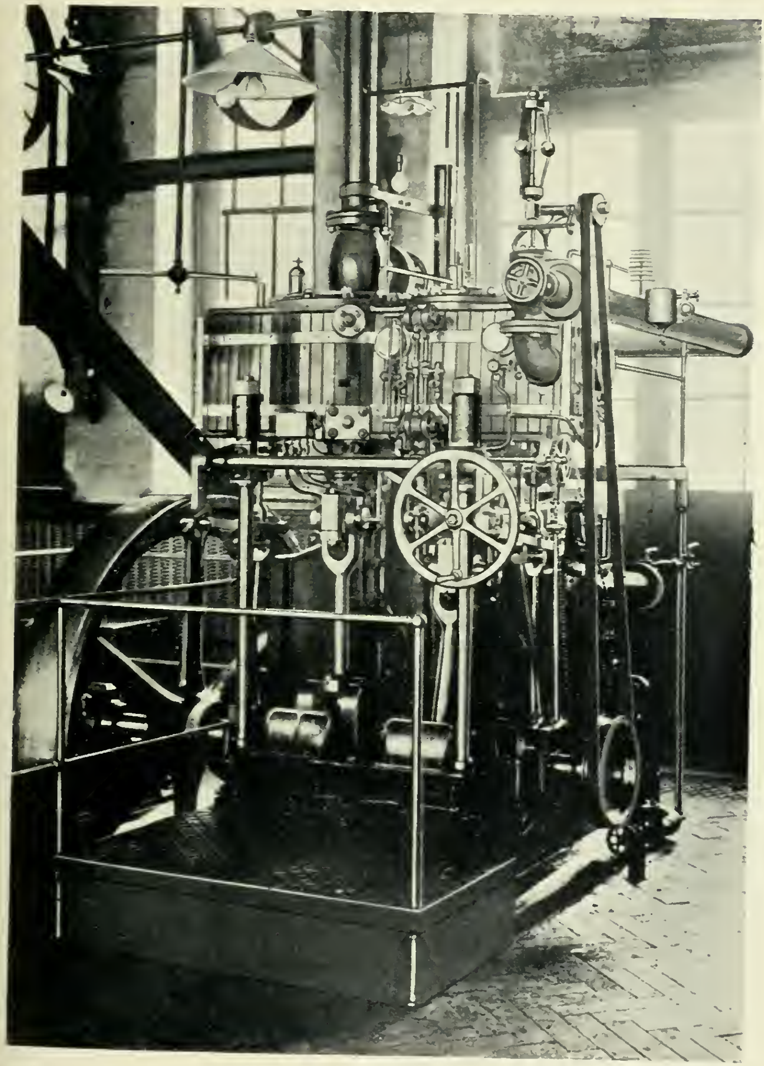


Plate 147.

Fig. 51.

Experimental Engine at University College, Sheffield.



MEAN - PRESSURE INDICATOR.

Fig: 52.
Differential Pressure Gauge.
Scale 1/3rd.

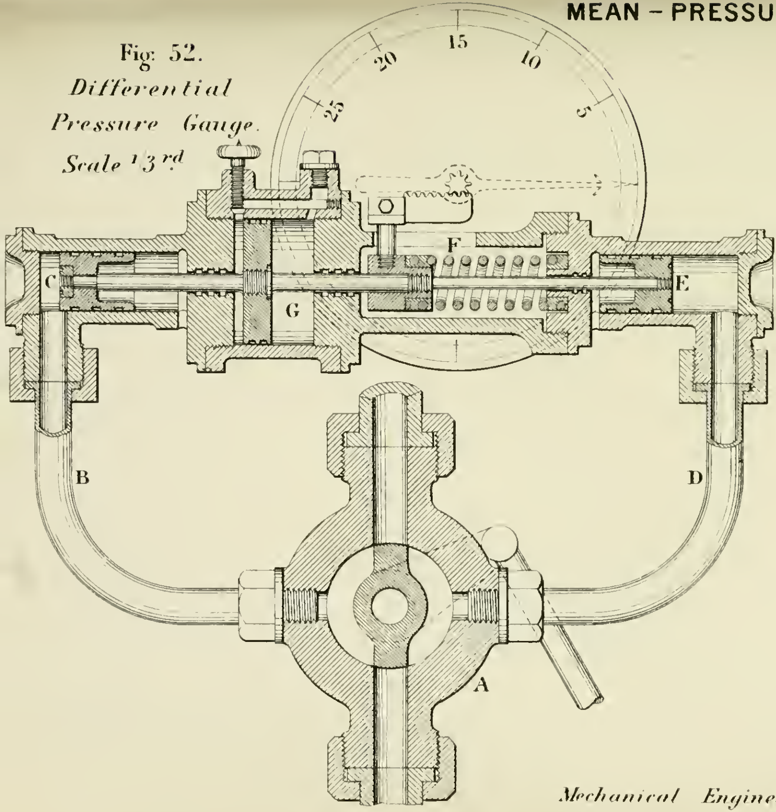


Fig: 53.
Syphon for Pressure Gauge.
Scale 1/8th.

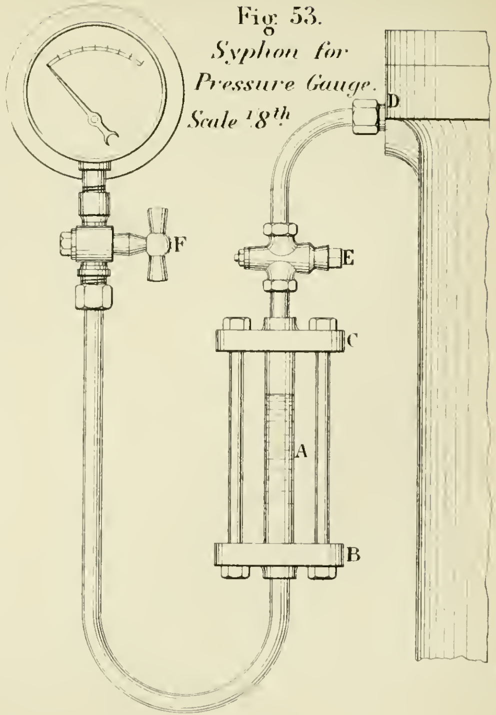


Plate 149.

MEAN-PRESSURE INDICATOR.

With Rotating Valves.

Fig. 54.

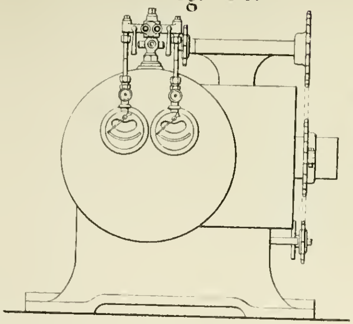


Fig. 55.

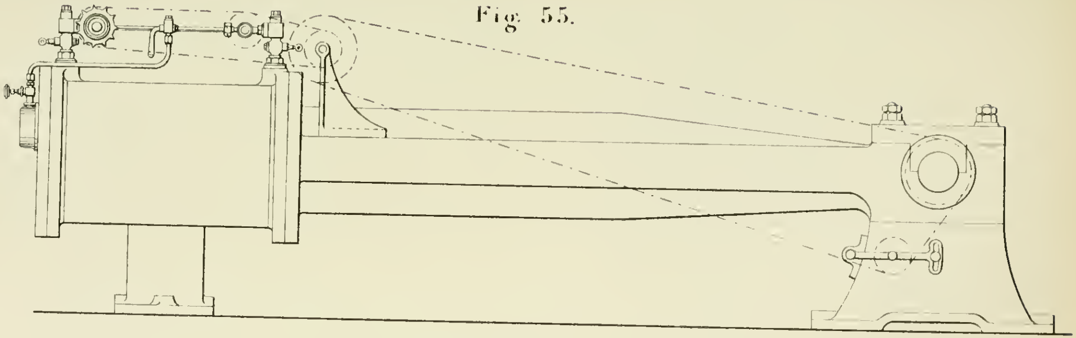
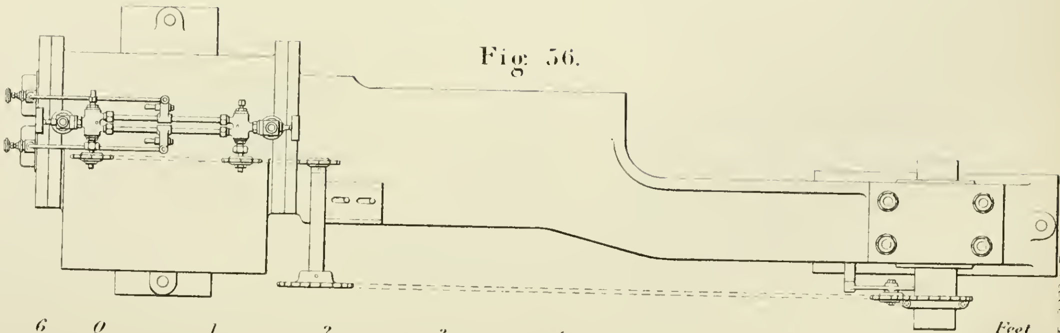


Fig. 56.



Mechanical Engineers 1899.

Scale 1/20th

Plate 150.

MEAN-PRESSURE INDICATOR. *Plate 151.*

Used on Experimental Engine, Plate 148.

Fig: 57.

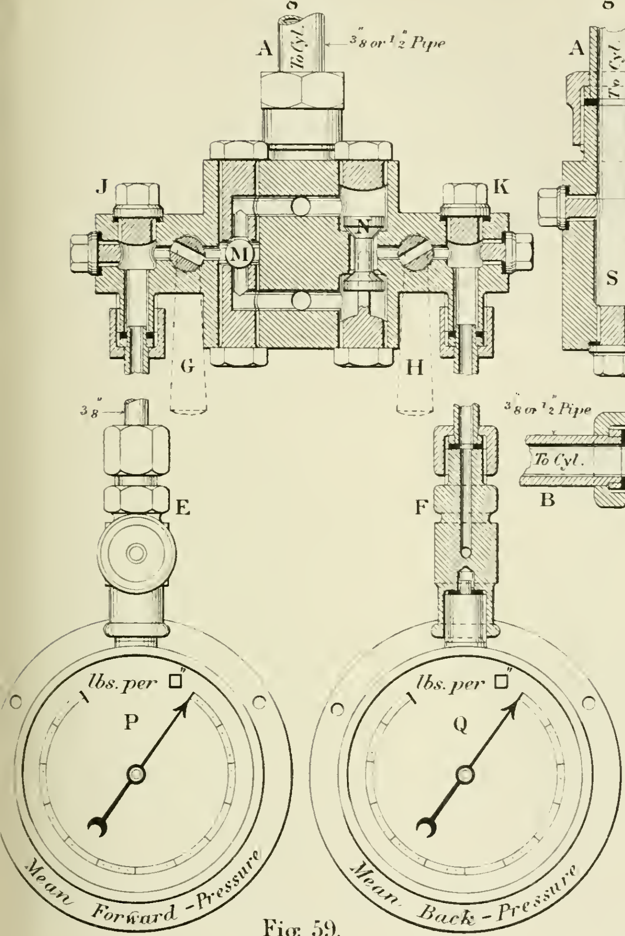


Fig: 58.

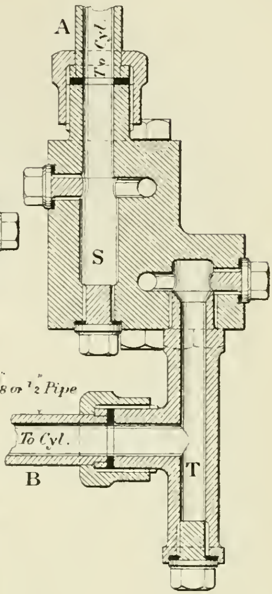


Fig: 59.

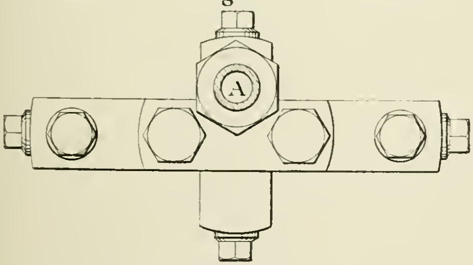
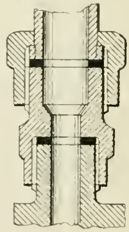


Fig: 60.
Section of Union for 3/4" bore Pipe.



Mechanical Engineers 1899.

Scale 1/3rd

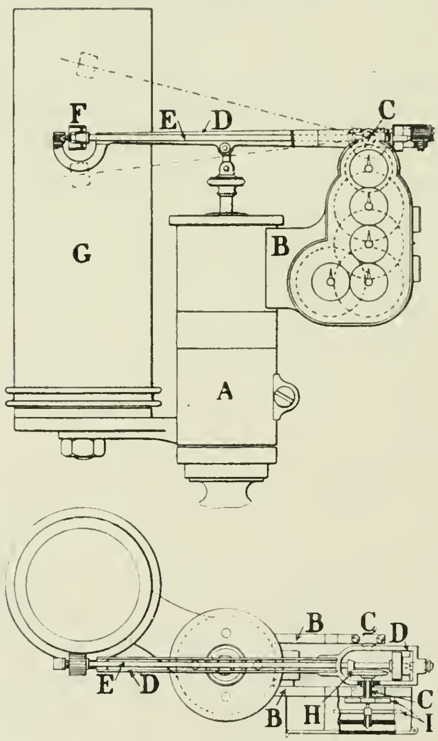
0 1 2 3 4 5 6 7 8 *Inches*

Mr. Henry Lea, Member of Council, was sure that every member present would sympathise with Professor Ripper in his endeavour to obtain from a steam-engine something in the nature of a continuous record of the mean pressure which, in the cylinder, was doing the work of the engine. In some kinds of engines, such as pumping-engines and probably marine-engines, it was not so necessary to have special apparatus of that kind, because the load was constant, and a diagram taken at one instant was exactly the same as a diagram taken a minute, or half-an-hour, or an hour afterwards. But engines with variable loads were more common than those in which the load was constant, and in these cases it was customary to take indicator diagrams, perhaps twenty or thirty, and to arrive at the mean results as nearly as possible. If the diagrams varied as widely as those illustrated in the Paper, then it was possible to run a planimeter over the whole of the diagrams in succession, and, dividing the result by the number of diagrams, to get the average area of the whole of them, which, multiplied by the scale and divided by the length of the diagram, gave the mean pressure. But that was a laborious process, and it was seldom found that each individual diagram on a paper was clearly separated from any other. A sort of cloudy line was obtained, perhaps a quarter of an inch wide, which might include twenty, thirty, forty, or fifty diagrams, and the remainder were perhaps fairly separated from each other. But it was difficult to tell how many were included in that cloudy area; therefore an instrument which would give an average result was, in the cases of engines which had an irregular load, a very great advantage. He therefore fully appreciated Professor Ripper's endeavours to obtain such a desirable result, and it impressed itself upon him more particularly because about twenty years ago he had the same desire, and tried to accomplish it in another way. Although his way was quite different from that of Professor Ripper, and was not altogether successful, it might be of interest to the members to know what that way was. A few years before that time, Mr. Storey brought out a continuous-indicator *—he thought the cost

* Proceedings 1871, page 75.

(Mr. Henry Lea.)
of it was about £40—which had to be carefully erected in the engine-room, and coupled to the two ends of the cylinder. Then it was supposed to be left there, and to give a continuous record of the area of all the diagrams which would have been taken in the same time by an ordinary indicator. In indicating steam-engines there was more than one object in view; first of all, it was desired to ascertain whether the valves were set correctly, and for that purpose an ordinary diagram was taken. Secondly, it was desired to ascertain what the mean pressure of the steam was in the cylinder. For that purpose a number of diagrams were usually taken. In

Fig. 61. *Continuous Indicator*, 1877.



order to supersede this last method, his idea was, that if something could be obtained which in about two minutes could be fixed upon the Richards indicator (the only reliable indicator at that time) in the place of the pencil parallel motion, and which would score up the total area of all the diagrams taken in an hour or two hours, or any other time, this would furnish, in quite a portable form, an apparatus which would show first of all, by means of the ordinary diagram, how the valves were set, and secondly, in a few minutes one could begin to take a continuous record of the total area of the diagrams described during any desired length of time, which total area, being divided by the number of diagrams taken, would give the average area of each diagram. The continuous recording gear, which could be placed upon the steam-cylinder of an indicator in place of the ordinary Richards parallel-motion carrier in less than two minutes, was shown in Fig. 61, A being the steam-cylinder of the Richards indicator, B an arm, C a pivot on which rocks a double lever D, with revolving spindle E. On the end of the spindle is a conical roller F, the cone of which coincides with two lines drawn from the pivot C. This roller is grooved longitudinally with very fine grooves. A piece of thin paper, saturated with oil, is put around the paper barrel G. As the steam forces the piston of the indicator up and down, and puts the lever into various positions, the surface of the roller is presented to the circumference of the paper barrel G at such angles that when the paper barrel is reciprocated by means of the cord, the roller revolves just like that of a planimeter, and the total revolution in one direction faithfully represents the area of the figure which would have been described on the piece of paper if a pencil had been put in place of the roller. It is only necessary to put a pair of bevelled wheels at H, driving some counter-work I, to get a record on dials of the total motion of the roller, which record is the total area of all the diagrams which would have been described by the pencil if it had been in place of the roller.

The full formula for calculating the I.H.P. would be—

$$\frac{Pa \times L}{33000} \times \frac{N}{T} \times \frac{A \times \text{Scale}}{l \times N} = \text{I.H.P.}$$

(Mr. Henry Lea.)
where Pa = Effective area in square inches of the piston of the engine.

L = Its length of stroke in feet.

N = Total number of strokes made (diagrams described) during the test.

n = Number of strokes per minute $= \frac{N}{T}$

A = Total area in square inches of diagrams taken and recorded.

l = Length in inches of each diagram.

T = Duration of test in minutes.

Obviously N cancels N, and no count of strokes need therefore be taken.

$$\frac{Pa \times L \times \text{Scale}}{33000 \times l}$$

can be worked out while the test is going on, producing a constant C. Then at the end of the test it is only necessary to perform this simple calculation—

$$\frac{C \times A}{T}$$

and you have at once the mean I.H.P., throughout the test, of that end of the cylinder to which the continuous indicator has been applied.

Suppose an engine running at 100 revolutions per minute to be tested for an hour, and a continuous indicator to be applied to each end of the cylinder, then the number of diagrams taken and recorded would be $100 \times 2 \times 60 = 12{,}000$. If the calculation of $\frac{C \times A}{T}$, which, with a slide rule, could be worked out in about ten seconds for each end of the engine cylinder, be compared with the labour of working out 12,000 indicator diagrams, he thought it would be agreed that the result was something worth trying for. He was very much pleased to find that when the apparatus was tried upon a pumping-engine the two results obtained, first from the ordinary indicator diagram, and secondly from the continuous indicator, agreed within half per cent. But then came his disappointment. He proceeded to try the apparatus upon an engine moving much more quickly, and then he found that the momentum of the roller caused it to continue

to revolve after the lever had ceased moving, and an error was thereby introduced which caused him to drop the whole thing.

Mr. Stephen H. Terry then described a dial steam-power meter designed by him in 1877 and shown in Figs. 62 to 66, pages 590–594. It was intended for use with pumping, winding, or marine engines, and could also with modifications be fitted to locomotives. The instrument was intended to register three things, namely:—(1) On the left-hand dial the mean effective pressure per square inch of piston area, as well as the mean effective pressure per circular foot of piston area; (2) on the right-hand dial the speed in feet per minute at which the piston is at any moment moving; and (3) on the central dial the indicated horse-power. In the case of double-cylinder engines, the instrument would be placed between the two cylinders, and branch steam-pipes would be fitted to both ends of each cylinder, and suitable stop-cocks arranged so that the power given off by either cylinder could be read off. The measuring apparatus is contained in the lower part of the instrument, that on the left measuring the mean pressure, that on the right the piston speed. The indicating apparatus which renders these measurements visible is shown on the upper part of Fig. 62, and consists of 3 similar pinions, 2-inch pitch circle, 32 teeth, 2 double racks, 2 fixed dials and a movable dial, and 3 paper drums, for recording the speed and pressure during every hour of the day.

The pressure-measuring part of the apparatus consists of a vertical brass cylinder, $1\frac{5}{8}$ inch diameter, *i.e.*, 2 square inches area and 3 inches stroke, with a piston attached to a long rod. The piston is steam-tight but nearly free from friction. The steam from both ends of the engine cylinder is led to this cylinder by means of two $\frac{1}{2}$-inch steam-pipes, and is distributed by the simple form of puff-and-dart valve which is driven to and fro for a stroke of $\frac{7}{16}$ of an inch solely by the difference in pressure on its two sides. Its ports are so arranged that the "steam" side of engine piston is always open to the under side of instrument's piston, while the "exhaust" side of engine's piston is open to the upper side of instrument's piston, see Figs. 63 and 64, page 591.

(Mr. Stephen H. Terry.)

Fig. 62. *Design for a Dial Steam-Power Meter*, 1877

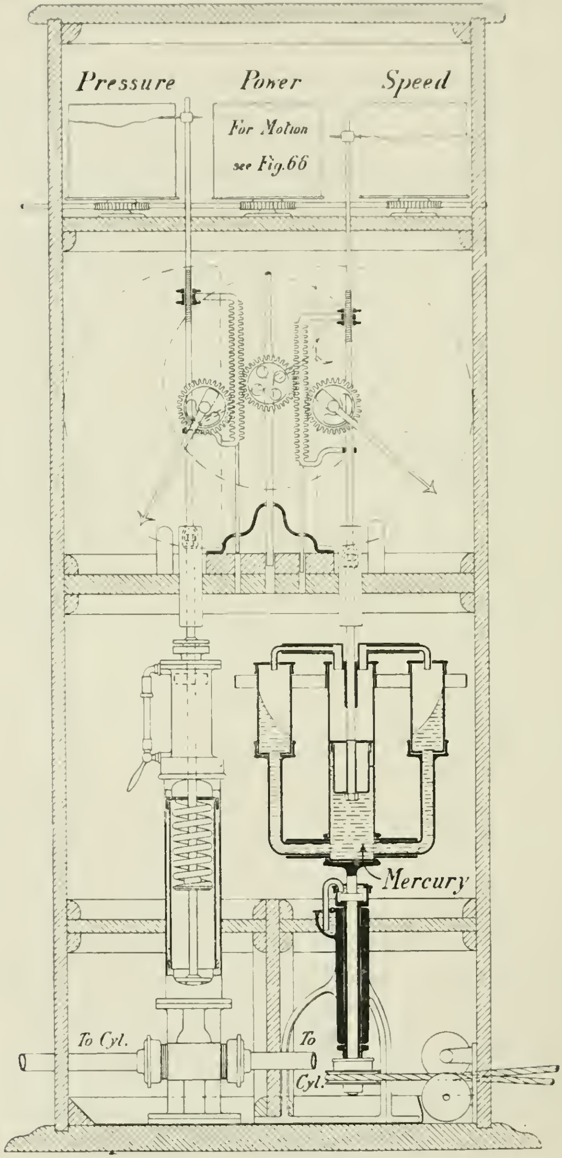
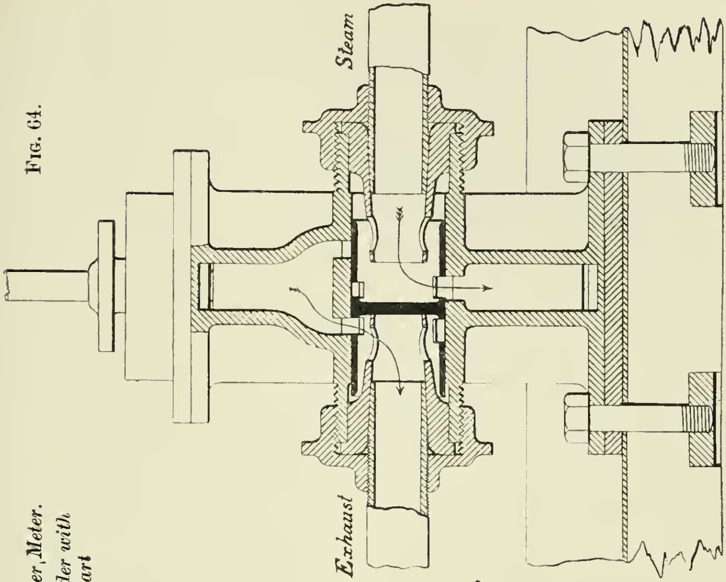


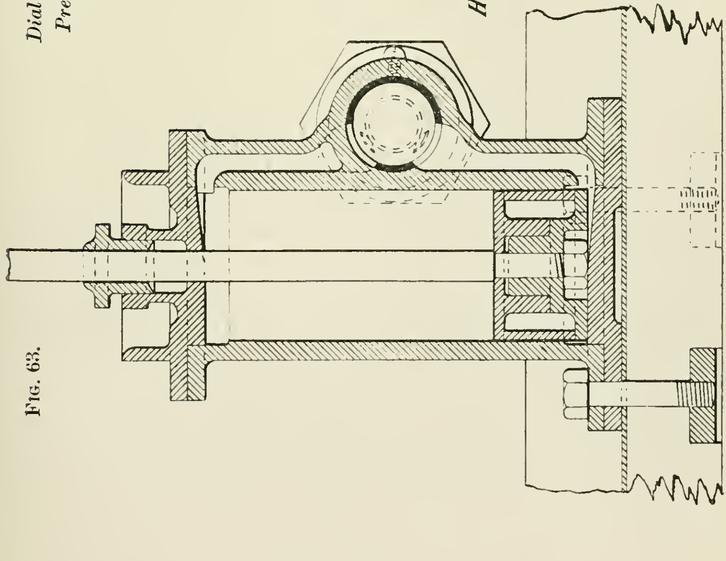
Fig. 64.



Dial Steam-Power Meter.
Pressure Cylinder with Puff-and-Dart Valve.

Half size

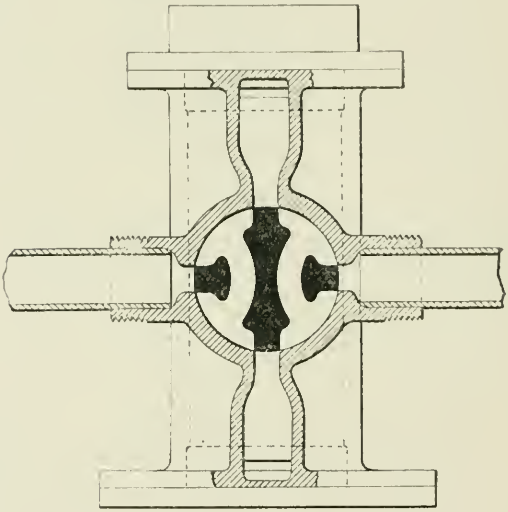
Fig. 63.



(Mr. Stephen H. Terry.)

If preferred, the other arrangement, see Fig. 65, can be used instead of the piston slide-valve for admitting and emitting the steam. It consists of a four-way cock, with the passages so cored out that there is no lap at the joint on the face, and thus so soon as the cock has closed one passage it opens the other, and as it will be on its centres at the same moment that the engine is passing centres, the momentary closing is of no importance. It may be revolved by a shaft and gear wheels from the engine or by a pitch chain, or it may

Dial Steam-Power Meter.
Fig. 65. *Revolving Cock.*



be reciprocated by an eccentric or other positive means. The long piston-rod of the instrument passes up through a stuffing-box, and carries a disc against whose upper surface a spiral spring presses, in such a way that when the piston-rod and disc are quite down, the spring is just free from contact with the disc. The piston-rod then passes up through an oil cylinder with a regulating cock, which arrangement prevents the rapid motion of the piston during every stroke of the engine from the variation in pressure, and causes the piston to take up a mean position,

being that due to the mean upward pressure of the steam, minus the downward pressure of the spring and the counter-pressure of the exhaust steam; this position can be the mean of a few strokes or of many according to the position of the regulating cock. At its upper end the piston-rod is coupled to a form of stirrup, in such a way that the rod can turn partially under the action of the spring, without turning the toothed rack or causing unnecessary friction in the guides. The apparatus for measuring the piston speed consists of three brass tubes, the central one $1\frac{5}{8}$ inch internal diameter, the side ones are each $1\frac{5}{32}$ inch internal diameter, the area of the first is therefore 2 inches, while that of the others is each 1 inch. These three tubes are connected together by telescopic tubes at their upper and lower ends, which allow the mercury and the air to pass freely from one to the other. The two horizontal screws shown are for adjusting the lateral distance of the tubes from the central one. A brass float carrying a long rod rests on the mercury in the central tube, and is free to rise and fall with the level of the mercury therein. The whole apparatus is put in revolution by means of the long spindle shown, at whose lower end is a pulley of such a size that the spindle shall make, say, two revolutions to every foot of piston speed per minute. The rod before-mentioned ends in a stirrup coupling. Both these couplings form part of long brass rods, square in their lower parts beneath the screwed parts; by means of the two nuts shown, a frame carrying a double-toothed rack is adjustable at any height on both these rods; the racks are guided vertically by the two tails shown. Into the outer teeth of these racks gear two similar pinions, which carry pointers, showing respectively the mean pressure and the piston speed on their two dials.

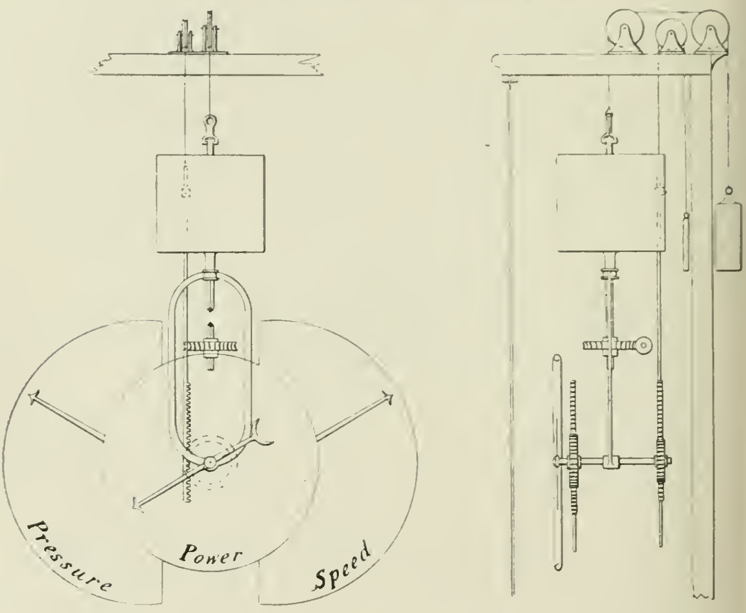
Into the middle teeth of the two racks gear the opposite sides of a third pinion. This pinion carries a movable dial which is free to rise and fall, and to partake of the motion of the two racks, and to show by its pointer the combined motion of the two on the scales; this dial is guided by the long or differential rod shown affixed to its back.

(Mr. Stephen H. Terry.)

To enable the central drum to record the H.P., it is arranged to rise and fall with the central dial, as shown diagrammatically on Fig. 66, the whole weight of these rising and falling parts being balanced by a counter-weight and cord leading over a pulley mounted on ball-bearings. To provide for the rotary movement of the paper drum, it can be driven by a square shaft on which it slides, or a slotted shaft with feather as used in self-acting lathes.

Dial Steam-Power Meter.

FIG. 66. *Gear for Power Drum, recording I.H.P.*



A fourth pinion keyed on the central arbor behind the dial pinion, gearing into a rack, gives to that rack carrying the pencil the combined motions of the other two racks, the vertical distance between the paper drum and the central dial arbor being maintained by a radius rod or banjo frame. The same result may be attained by a continuous metallic cord having the central part made fast and with three turns winding on or off between a drum on the central

spindle and a pulley on the paper drum carriage above, causing a vertical slide carrying a pencil to rise and fall.

The tubes in which the stirrup couplings are placed have for their object the prevention of the steam or dust, which may come from the glands and belt below, from getting amongst the wheel work; the upper end of these tubes is covered with a disc, in the centre of which a square hole is filed to act as a guide to the long screwed rods, and to prevent them from turning. The marking of the central dial has to be done experimentally.

Professor Robert H. Smith said he had only one or two remarks to make, one of which he thought was rather important. In the first place he would like to suggest, with reference to what Mr. Henry Lea had said, that he had the great privilege of having an opportunity of using Mr. Lea's instrument, Fig. 61, page 586, some time ago and testing its utility. He would like to suggest that possibly the use of aluminium for the roller and the other reciprocating parts might give a greater chance of utility with engines of high speed. With regard to pressure-gauges, Professor Ripper had referred to the doubts that were commonly entertained as to their accuracy, which he thought was a rather more important question than was indicated in Professor Ripper's Paper. It was quite easy, by paying a proper price, to get steam-gauges that indicated accurately. He had had them over and over again. But with the best that he had been able to obtain in the market he had not found them maintain their accuracy over a very long life. The difficulty was not to secure a sufficient standard of accuracy when the instrument was new, but from use the elasticity seemed to deteriorate, and an error crept into the indications in the course of a few months if the instrument was in constant use. He would also like to ask Professor Ripper to give some information in his reply as to whether there was much leakage past the oscillating and rotating valves of his instrument. He was sorry Professor Ripper had not given the theory of his instrument in the Paper. The author had not said why the instrument gave the true time-average of the pressure. It was most important to establish that it did so. The comparison between the true time-average and the true

(Professor Robert H. Smith.)

distance-average which Professor Ripper had given was most interesting; it was one that he had never worked out himself in nearly so complete a fashion, although he had made similar calculations for a series of cases in connection with variation of cylinder temperature in the discussion upon Mr. Willans' Paper on steam consumptions.* He was extremely pleased with the results Professor Ripper had obtained, showing that there was such a close approximation between the two, and that the one could be converted into the other with the degree of accuracy that had been indicated. But the question as to whether the instrument really gave a true time-average was a fundamental one. The whole theory of the instrument, he thought, depended very largely upon the column of water in the syphon. It depended upon the mass in the instrument to which the variable pressure was applied, and which was left movable under that variable pressure. This mass was exposed throughout any given length of time to a succession of steam-impulses, and the mass acquired, in the direction of those impulses, a total or integral momentum equal to the time integral of the impulses of pressure, however variable the pressure might be. This time integral might be written $\int Pdt$, where P is the varying steam-pressure on the top of the water column in the U tube. The same mass was pressed in the other direction at its other end by the elastic tube of the instrument, and the time integral of this elastic pressure upon the movable mass was also the total momentum that it received in this opposite direction. As the mass at the end of any short or long time had not received any integral momentum in one direction or the other, there was a complete or exact equation between those two total impulses in the two opposite directions. By the throttling the spring or elastic force was reduced to almost absolute constancy, so that its time integral was simply a constant force multiplied by the time, or St where S is the force exerted by the elastic tube. Equating this to $\int Pdt$, it is seen that the spring force $S = \frac{\int Pdt}{t}$, the accurate and theoretically correct mean average of the variable pressure. It was true that other forces

* Proceedings Inst. C.E., vol. xciii., page 285.

besides the elastic force of the tube came into play to hinder generation of momentum in either direction, namely, the frictional and viscous fluid resistances to the to-and-fro motion of the water along the tube and through the throttles. But these forces were in the first place small, being proportional to a power of the velocity between the first and second, whereas the actual velocity of to-and-fro flow was reduced to an extremely small amount by reason of the throttling; and secondly (and of still more importance) the peculiarity of these fluid viscous and frictional forces was that they yielded, slowly but surely, to the action of even the smallest unbalanced external force. Thus, if the above two integrals were unequal in the smallest degree, the overbalance would produce movement in the mass in spite of the viscous resistances, the movement developing slowly in proportion to the smallness of the overbalance. But even after a long time the mass maintained exactly its original mean position; this proving that in the integrals taken over any but a very short time, there was the above exact equality.

Mr. C. F. Budenberg believed that the pressure-gauge as an instrument of measurement had been unduly maligned by engineers in general. He could not agree with Professor Smith's statement that all gauges, however well made, would show a considerable error after a number of months' continuous use (page 595). His firm had in continuous use a large number of pressure-gauges with 10-inch dials for calibrating and testing purposes, and they had absolutely no difficulty in securing permanent and perfect accuracy in these gauges. The scale markings of these gauges consisted of very fine dots which would reveal the slightest error, and they were tested twice weekly by comparison with mercury columns, any slight errors being corrected as they were discovered, by erasing the false marks and putting in fresh dots. Only the other day he took occasion to examine some of these gauges, having dials which were placed in ten years ago, and found that the total variations of the indications (shown by the erasures) during the last ten years had been extremely small, probably not representing more than $\frac{1}{4}$ or $\frac{1}{2}$ per cent. of the

(Mr. C. F. Budenberg.)

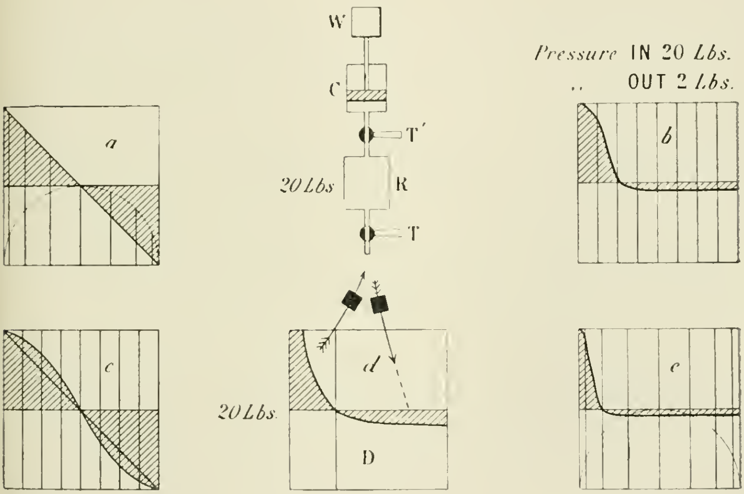
total pressures. But these gauges were carefully made and very well cared for. They were not subject to heating, and in the ordinary way the pressures went up and down fairly steadily. His contention was that if a well-made gauge was used for a fairly steady pressure, and was kept cool and received reasonable care, it could be relied upon to give permanently accurate readings. Of course, if the spring of a gauge was too weak for the working pressure it was required to withstand, it would gradually give way, but there was no reason why a sufficiently strong spring should not be used, combined with sufficient multiplication of the movement of the spring, to obtain the required range of scale on the dial of the gauge. He could connect a 10-inch pressure-gauge to the pump of a mercury column, and if the pressure were accurately set by the pressure-gauge to a pressure of say 150 or 200 lbs., he would guarantee that the registration of the mercury column would not differ by more than $\frac{1}{4}$ lb. at the outside, an experiment he would be glad to perform in the presence of any member. That he thought proved that it was possible to obtain accurate and consistent readings by means of pressure-gauges.

Mr. HENRY DAVEY, Member of Council, fully appreciated Professor Ripper's labours, which were most valuable. The Paper had been a most interesting one, and he hoped Professor Ripper would not think that anything he might say in criticism of the system would be said in any way derogatory to the Paper.

It was a very usual practice to ascertain the mean pressure from hydraulic mains and steam-pipes subject to quick variation of pressure by throttling the pressure-gauges, and doubtless an approximation sufficient for practical purposes was thus obtained; but for the purpose to which Professor Ripper had applied the principle a more accurate method was desirable. Professor Ripper had designed a mechanism with a view to more perfect results than a mere throttling of the gauge would give, but in comparing the results obtained with his apparatus with that obtained with the indicator, he had found that there was a discrepancy. Assuming the indicator to give correct results, he had, as Professor Smith had

pointed out, constructed a theory, but had not given a proof of it. Professor Ripper's theory (page 573) related to the difference between the time-pressure and the distance-pressure diagrams. Mr. Davey did not think that formed the basis of a correct theory. To test it extreme examples should be taken. In Fig. 67 *a* let the distance-pressure indicator diagram be a triangle. The positive and negative effects are then similar. They are also similar on the time-pressure diagram, *c*. If we take a distance-pressure diagram, *e*, and its time-pressure diagram, *b*, we see that the positive and negative

FIG. 67.



effects are greatly dissimilar. The more nearly the upper line of the diagram approaches a straight line, the more nearly will the positive and negative effects coincide.

The general principle of Professor Ripper's apparatus might be illustrated in *d* by W representing a weight and C a cylinder and piston of the pressure-gauge; R the syphon reservoir, T T[1] the throttling-cocks, and D the indicator diagram. It was a necessary condition for the working of the apparatus that there should be an influx and efflux from the reservoir R through the throttling-cock T as indicated by the arrows. To maintain the weight W in a position

(Mr. Henry Davey.)

that should indicate the mean pressure on the gauge, the influx must be the same as the efflux. The influx in this example would take place under 20 lbs. pressure, whilst the efflux would be under 2 lbs. pressure, but the efflux would occupy a longer time. There must be an equation for those effects, and perhaps Professor Ripper would work it out. He himself had taken extreme examples that the theory might be tested.

Having said that much, he would just say a word or two from a purely practical point of view. Assuming that the instrument could be made to work quite perfectly under any given condition, say with dry steam, what would be the result when priming occurred? Water would have to pass through the cock T instead of dry steam, and that would tend to vitiate the result. Referring to Professor Ripper's diagram, Plate 141, it was necessary that the valve A should open exactly at the beginning of the stroke, and close at the end. There was always the risk in the hands of inexperienced men of having the valve not perfectly adjusted. It ought not only to be perfectly adjusted, but it ought to be steam-tight. Another disturbing factor was the want of proper adjustment in throttling. In the hands of experienced men there would probably be no difficulty.

The President thought that the members would be glad to hear that M. Edouard Sauvage, the eminent French engineer, who, he was glad to say, was to be recommended for election into the Institution shortly, had sent a communication with a diagram, which had been placed on the wall. The written communication, with a copy of the diagram, would be appended to the report of the discussion. [*See page* 607.]

Mr. W. Worby Beaumont asked whether Professor Ripper had tried his instrument for gas-engine or oil-engine purposes.

Mr. John G. Mair-Rumley, Member of Council, said there was a mean-pressure indicator made by Professor Boys and Mr. Cunynghame, which he had tried, and which he thought might be known to Professor Ripper. It was an integrating machine, and gave very

good results, but he never felt inclined to trust it until he had taken an indicator diagram for comparison. As regarded the accuracy of throttled pressure-gauges, he had made so many experiments with throttled gauges against solid columns of mercury, both with water and steam pressures, that he did not hesitate to say Professor Ripper was perfectly right in stating that a throttle-gauge would give practically the true mean-pressure. It was well known that the ordinary dial vacuum-gauge of an engine was always throttled down, and, when connected with a mercury column, it would be found one tallied with the other. There was no doubt that a mean-pressure indicator of the type shown would be an exceedingly valuable thing for engines, because the apparatus was so absolutely simple, and being a throttling-gauge he should not have any hesitation in saying that the author was right in his opinion of its accuracy. But with a different form of instrument, such as a disc and roller, there was so much complication that the author's device, he thought, was the best form of mean-pressure indicator to put on a steam-engine; and the clever arrangement the author had schemed out for separating the steam line from the vacuum line gave a limited variation of pressure to deal with, and for compound or triple engines undoubtedly the results obtained by throttled gauges would give most useful results to steam users.

Professor W. W. F. Pullen thought that most of those who had already spoken had forgotten that after all, in finding the I.H.P. of the steam-engine the diagram had to be averaged, which was generally done with a planimeter. In more than one form of instrument, one had to measure off the distance between two points, the starting and finishing point of the tracing stilus. With an ordinary indicator scale for a No. 90 spring, one could scarcely read with greater accuracy than 1 lb. per square inch, the thickness of the pencil line making quite this difference. Professor Ripper's indicator gave that very easily with a well-made gauge, and therefore he thought Professor Ripper's instrument was quite comparable in that respect with the ordinary indicator. He thought the instrument also fitted into a gap which required filling up for

(Professor W. W. F. Pullen.)
high-speed engines. Everyone knew, or ought to know, the possible errors which could be produced in taking an indicator diagram from an engine running at 400 or 500 revolutions a minute. The higher the speed the more accurate did Professor Ripper's apparatus become. Therefore he thought there was a very great field for his apparatus in conjunction with high-speed engines, especially such as are used in torpedo-boats where space is limited. He should like to ask Professor Ripper what was the probable error, if there was an error at all, when the diagrams were constantly varying. He had himself seen diagrams taken from an engine running under a constant load with a throttling governor, in which the variations had been as much as 10 to 15 per cent. in consecutive diagrams, due to the hunting of the governor. He would like to know how the mean-pressure indicator would deal with that constant variation. He imagined it would deal with it satisfactorily. Then again, there was the question in which the valve-gearing had been badly set. On one side there might be a fairly fat diagram and on the other one a very lean diagram; so that the two together, if the sectional area of the piston-rod was taken into consideration, would give something which was a little different from the true mean-pressure, although the error would be small. He should like Professor Ripper to say something on those points. It had not been mentioned so far that Professor Ripper's indicator would get over a very great deal of inconvenience in indicating a locomotive. The ordinary method of indicating a locomotive was one of very great inconvenience, but in Professor Ripper's system the pipes could be taken to gauges on the foot-plate and the mean-pressure read off without any difficulty at all. Some gentlemen had expressed some sort of doubt as to the effect of throttling, and had suggested that the variation between two throttling-cocks might introduce some considerable error. He would suggest putting on more than two throttling-cocks, and these might take the form of discs with small holes in them. The greater the number of throttling-discs or cocks, the more nearly stationary would the gauge-needle become, and the more easily the mean-pressure obtained.

Mr. Robert Holden said he had had a great deal of experience with indicators, and appreciated Professor Ripper's Paper very much. But there was one thing he failed to find, that the author did not clearly show the initial steam-pressures in cylinders as compared with the dial pressure-gauges on boilers. In indicating new and first-class engines, it was now customary for the owners to ask that a complete set of diagrams should be left by the builders after the work was finished. The duty of the indicator was not confined to showing the power given off by the engine, but also to reveal fully the true setting of the valves for compression, admission, points of cut-off, leakages, and vacuum. These matters were not shown by the mean-pressure indicator, and with his experimental compound-engines Professor Ripper had not given them any readings from the low-pressure cylinder.

With regard to the throttling of gauges, that was a thing most engineers wished to dispense with. He agreed with the last speaker that a series of special cocks might overcome it, or that Professor Ripper might devise something with small openings. Dial gauges when placed near cylinders were soon out of order by the oscillation caused through the sudden check on the flow of steam at cut-off and reversing of stroke, and in that case throttling was necessary. The best made gauges were not always reliable. He remembered a case near Manchester where old boilers were taken out and replaced by new ones having a much increased pressure. When the engines, which had been reduced in diameter of cylinders, were indicated, there appeared to be a loss of about 10 lbs. between the indicated pressure in the high-pressure cylinder and the registers of the gauges on the boilers. This was thought to be due to the intricate ports and crippled passages through an old throttle-valve, which had been in use previously. But when this was removed, and a new wing-valve fixed, the pressure still remained the same. When the boilers were indicated, the two gauges were found to register 8 lbs. in advance. The Richards indicator-spring being 2 lbs. (nearly) strong, made the loss look like 10 lbs. In his opinion it was always best to indicate the boiler first, and not remove the paper after drawing the atmospheric and steam line carefully, and then take the cylinder

(Mr. Robert Holden.)

diagram between the lines. Whether the spring was a little strong or weak it made no difference, the loss being clearly shown in the most satisfactory way. It was a common occurrence for an engineer to see a battery of boilers and to hear from the stoker that all the pressure-gauges were more or less forward and late, except one which "he knows to be right." He would rather place reliance on a good modern indicator of the "Tabor" type for accurate results than on dial pressure-gauges, especially if the latter required throttling.

Professor Ripper thanked the members for the kind way in which they had criticised his Paper. With reference to Mr. Lea's interesting description of the way in which he tried to solve the question some twenty years ago or more, he was sure that anyone who had spent a long time in trying to overcome difficulties must appreciate the amount of labour spent, and he thought the members would sympathise with Mr. Lea that his experiments were not more productive. It was one of the penalties of inventing, that it was very rarely productive. With reference to Professor Smith's remarks (page 596), he thanked him particularly for explaining so lucidly the influence of the mass momentum. One question Professor Smith asked was with regard to the leakage of the valves. If the valves leaked a little—and they must necessarily leak a little in the same way that an indicator-piston leaked a little—the difference was absolutely nothing on the exhaust-gauge, because any leakage of the valve went into the exhaust at the engine. But, if there was anything like serious leakage on the steam side, the pressure fell in some proportion to the amount of leakage, and the point was to make leakage as small as possible. He was interested in Mr. Davey's remarks (page 599) and in the careful diagram, Fig. 67, he had drawn to illustrate them. Mr. Davey explained very clearly a case which he himself would admit was a very unusual case. Every instrument had its limitations. The indicator itself had its limitations; high-speed engines were one of the directions in which the indicator could not be made very much use of. An engine, with such a diagram as that to which Mr. Davey had very properly called attention, was one of those cases where he should not dream of

using that instrument. It was interesting and valuable as an addition to the discussion, and showed one example of the kind of work which, on the whole, the instrument was not suitable to deal with. He should like to say one or two things showing what the instrument was suitable for. In the first place, on his engines which were fitted with the mean-pressure indicator, when he went into the engine-house he saw instantly what was the condition of things—whether the engine was running light, heavy, or medium load, or how it was running. One could see instantly the condition of things in the engine-house without requiring any indicator diagram to be taken; one could see whether the load was a steady load or an unsteady load. If it was a compound or triple expansion, or a four-cylinder engine, it could be seen at once how the distribution of the power between the engines of the set was arranged. For example, it was possible that nearly the whole of the work was being done with one engine instead of being properly distributed between the engines—a thing that not unfrequently happened. Every engine had its best load—its rated load. He had a mark on his mean-pressure gauges which indicated the rated load of that engine, and on going to the engine one could see at once whether it was running at that load, or very much below or above it, and could make what necessary alterations might be required. If anything suddenly went wrong in the engine it could be instantly located; or one was very much assisted in locating it by seeing if it was here or there, or inside the engine or not. If the top and bottom cocks of the cylinder were closed alternately, and the reading of the gauges taken, and if the reading of the gauges was the same, it was fairly probable that the valve-gear was properly set. If there was a large difference between them, then it would be known something was wrong. In connection with trial trips he ventured to say that anyone who had had experience with trial trips, and knew the number of diagrams which had to be taken during, say, a thirty hours' trial with a diagram every quarter of an hour from each end of a four-cylinder engine—perhaps a number of such trials in succession—knew that the number of diagrams and the amount of labour were very great

(Professor Ripper.)

indeed. If at first a few sets of indicator diagrams were taken and the gauges were compared with those sets, he ventured to think that having once seen the relation between the indicator and the gauges, it was not necessary to take diagrams every ten minutes or a quarter of an hour, but at much longer intervals, and yet an equally accurate result could be obtained. Any slight fluctuation of power from time to time was instantly shown by the finger steadily moving one way or the other, according to the change of power. In reply to Mr. Davey (page 600) he should like to point out that the finger of the gauge was not still; it was always in a state of slight tremor, and the more the cocks were opened the greater the arc of movement. A primary necessity for the instrument was that the finger should be always slightly on the move to show it had life in it. He had not himself found any difficulty about skilled men being able to regulate the cocks, because his students regularly used them and made comparisons, and it generally came out very close indeed to the result obtained with the indicator.

In reply to Mr. Beaumont (page 600) he had not tried the instrument on gas or oil engines. It would have to be modified in form to be applicable to such engines. In reply to Professor Pullen (page 602), the more variable the load on the engine, the more frequently should the gauge readings be taken, or if the variations were uniform in range, the mean of these would be read from the gauge.

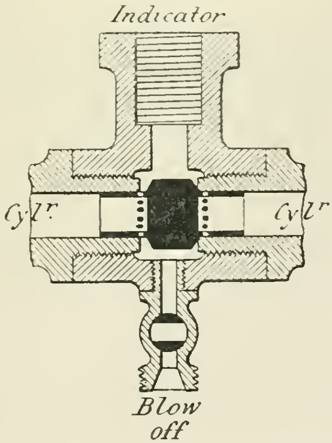
In conclusion he thanked the members for the attention they had given him.

The President said the members would all agree that the discussion had been a most useful and practical one, and they would record their thanks to Professor Ripper for his kindness in reading the Paper.

Communications.

M. Edouard Sauvage wrote that M. Janet at the Creusot Works had made some experiments of the same kind as those made by Professor Ripper. The indicator was often required to show only the work done, that is to say, an instrument giving this mean pressure would suffice, and would have the advantage of furnishing directly the desired value. Attempts had been made to obtain this direct reading by throttling the sectional area of the passage connecting the indicator with the engine cylinder. As this section became narrower the amplitude of the movement of the indicating pencil was reduced. To obtain clear results it had been found necessary to separate the forward and the return strokes of the piston. In M. Janet's apparatus, tried at Creusot, a small automatic valve, shown in Fig. 68, put the indicator in communication alternately with

Fig. 68.

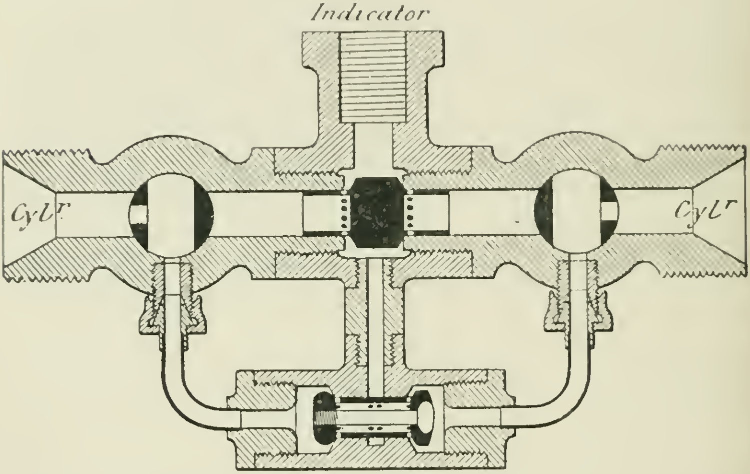


the two ends of the cylinder during each stroke of the piston. It would appear difficult to determine *a priori* the value of the indication thus obtained when the amplitude of the oscillation had almost vanished. Experience seemed to point out that in practice this indication very nearly approached the mean-pressure during the

(M. Edouard Sauvage.)

stroke of the piston, or rather the mean value of the two mean-pressures for the two ends of the cylinder. From this indication must be deducted the mean-pressure during the exhaust, and this could be indicated in a similar manner by putting the apparatus in connection with the cylinder during the return stroke by means of a second automatic valve shown in Fig. 69. In engines without compression, such as

FIG. 69.



the Corliss, the back-pressure, being almost uniform during the whole of the return stroke of the piston, was easy to measure; the first arrangement on the first figure with only one automatic valve was then sufficient. In these records the ordinary indicator would be useless; a pressure-gauge sufficed. A self-registering pressure-gauge would record in a continuous manner the work done by the steam. Fig. 68 showed the distributing valve for obtaining mean indication during the stroke of the piston, the apparatus being in communication with both ends of the cylinder; the valve put the indicator alternately in communication with the end where the highest pressure existed. Fig. 69 showed the distribution valve for obtaining the mean-pressures during the forward and return stroke of the piston; the lower valve put the indicator in constant communication with that side of the piston where the lowest pressure existed, when the two three-way

cocks were placed in the position shown. M. Janet made his experiments on a Corliss engine, and it was obvious that his automatic valves would not work properly when compression raised the pressure on the resistance side of the piston above the motive pressure.

Mr. Alfred Bache wrote to ask how in long-stroke engines (page 570) loss of pressure through excessive length of the pipes attaching the instrument to the cylinder was prevented by substituting separate valve-boxes, one at each end of the cylinder, instead of a single valve-box situated midway in the length of the cylinder. On previous occasions attention had been drawn to the loss of pressure in ordinary indicator diagrams when the connecting pipes were small and long (Proceedings 1886, page 364, and 1896, page 490); and to the consequent importance of placing the indicator direct upon each end of the cylinder, with the shortest possible length of connecting pipe. But in the present instrument the valve-box itself appeared from this point of view to constitute nothing more than a portion of the passage through which the steam had to travel from the cylinder to the pressure-gauge; and the length of the whole passage would be measured from the cylinder exit and through the valve to the surface of the water in the syphon of the gauge. In the long-stroke arrangement shown in Figs. 8 and 9, Plate 142, this length would apparently be the same if there were only a single valve-box placed midway in the length of the cylinder. For shortening the travel of the steam therefore, it would seem presumably necessary to duplicate the pair of pressure-gauges as well as the valve-box, attaching one pair of gauges direct to the valve-box at each end of the cylinder. In the Paper however there seemed to be no hint of any such duplication of the gauges. An elucidation of this point by the author would be welcome.

Mr. Frederic Strickland wrote that he would like to know whether Professor Ripper had made any experiments with his method of indicating on engines running at high speeds. The experiments quoted that the engine had been running comparatively slowly, and it seemed to him that this method of indicating should

(Mr. Frederic Strickland.)

be of greatest service in engines running so fast that indicating by the ordinary methods was difficult. His own work had lain principally in engines running at speeds of from 400 to 800 revolutions, and it was extremely difficult to get any reliable data as to their powers in the short time usually at disposal to try them. Unless any unforeseen difficulty occurred, it should be possible by Professor Ripper's method to get much more accurate results than by an ordinary indicator even when working at its best. At low speeds the latter might be an accurate scientific instrument, but at high it was certainly not so. Not only was the diagram disturbed by the momentum of the pencil and its motion gear, but the stretching of the cord often displaced the diagram longitudinally, so that really actual results were impossible. In some so-called high-speed indicators there was hardly an attempt to mitigate this error, so that at 500 revolutions they would displace the point of cut-off over an eighth of a stroke longitudinally, while giving a diagram that looked all right. As the speeds went up, the diagram had to be smaller until at 800 it was about one inch each way. How could this be measured really accurately? Even then it was difficult and troublesome to get any diagrams at all in the engine-room of small boats of all kinds, as there was very little room and the dampness of the air made the paper tear. If one could get the I.H.P. within even 5 per cent. without taking diagrams or working them out, it would immensely facilitate progressive speed trials in small craft. As the steam-launch was the parent of the destroyer, and the latter was the probable parent of the future high-speed passenger-boat, this was a matter of importance. He would like to know whether the author had ever tried putting his pressure-gauge upside down. It had seemed to himself that this was one of the simplest ways of syphoning a gauge, and had many advantages. As the gauge would get full up with water there would be no possibility of the enclosed air blowing the water out. It would also be possible to fill the gauge and tube, if desired, with oil, so that it could not evaporate. That would perhaps simplify the throttling. The dial of course would have to be made to read right way up. He thought the thanks of all engineers, especially high-speed engine builders, were due to

the author for investigations which he believed would immensely simplify their work.

Professor Ripper wrote that with regard to the interesting illustrations sent by the French engineer, M. Sauvage, he might say that he had a somewhat similar instrument at work on his own engine, for which he had obtained provisional protection in October last. An illustration of this instrument was shown in Plate 151. It consisted of a valve-box which was connected by pipes A and B respectively to the two ends of the engine cylinder. The valves in the valve-box were two in number, namely a ball-valve M working with a very small movement between two seats, and which dealt with the forward-pressure steam; and a double-beat valve N working on inside conical faces between two seats, and which dealt with the back-pressure steam. Both these valves worked together, and separated simultaneously the two effects, diverting the forward pressures continuously to the forward pressure-gauge P and the back pressures continuously to the back pressure-gauge Q. Suppose the forward-pressure steam was on the top side of the valves M and N and the back-pressure steam below the valves, then the forward pressure, being usually higher than the back pressure, pressed the valve M against its bottom seat, and the steam-pressure was communicated direct to the forward pressure-gauge P. At the same time the valve N was pressed downwards upon its upper seat, and the passage was thus opened through its lower seat, and there was now free communication with the exhaust side of the engine and the back-pressure gauge Q. A reversal of the pressure caused an upward movement of both valves, again diverting the forward and back steam-pressures to the gauges P and Q respectively. In order that water might be retained in the syphons and the gauges prevented from becoming unduly hot, cocks G and H were fitted and were throttled just sufficiently to prevent loss of pressure on the gauge. The fine adjustment was made with cocks E and F. To prevent dirt of any kind getting to the valves, dirt pockets S and T were arranged. Plugs J and K were used for filling the syphons with water on starting. This instrument

(Professor Ripper.)

assumed that the forward-pressures were always greater than the backward-pressures. Where there was a large compression an error was introduced. The difference between his own arrangement and that of M. Janet was that M. Janet appeared to have been using an indicator, and to have been taking the forward and backward readings on the same indicator as separate and not as simultaneous operations. His own experience of the results obtained with indicators was far from encouraging; and he had long abandoned them in favour of the pressure-gauge, in combination with a system of double throttling of the syphons.

In reply to Mr. Bache (page 609), when the instrument consisted of a single valve-box, midway between the two ends of the cylinder, the pipes connecting the valve-box to the cylinder ends contained steam, the pressure of which varied each stroke through all the ranges from initial to exhaust pressure. When however there was a separate valve-box at each end of the cylinder, the steam from the driving side, once passed through the valve-box of the instrument, did not fall so low as the pressure of the exhaust, because the driving steam from the other end was admitted to the steam-pipe before the pressure in the pipe had fallen fully to that of the back-pressure on the piston. To secure this result with absolute certainty it was usual to give the valve of the instrument a small amount of lead.

Mr. Strickland had suggested (page 610) that the pressure-gauges should be turned upside down. This it would be seen by the illustration, Plate 151, had already been done, and had been found to work most successfully, but even this arrangement was imperfect unless accompanied by the system of double throttling, because otherwise the syphon would remain empty, and the gauges would get very hot.

With reference to the speed at which experiments had been made with this instrument, he had had it in successful work for some time on an engine running at 280 revolutions, but so far had not had an opportunity of testing it at any higher speed.

MEMOIRS.

Robert Bettig was born in Barcelona on 11th June 1870. He received his technical education from 1885 to 1887 at the École Industrielle des Vosges, Épinal, France; and from 1887 to 1889 at the École Supérieure de Commerce et de Marine, Marseilles. For the two following years he was engaged in practical engineering at the works of Mr. Alesandro Wohlgemuth, engineer, machinist, and ironfounder, Barcelona, Spain. As a graduate of the two above colleges, he served in the French army for twelve months in 1891–92, instead of for three years. From January 1893 he was engaged with Messrs. John M. Sumner and Co., first in their Manchester office, and afterwards from April 1894 as manager of their branch house at Lille, where his death took place on 21st July 1899, at the age of twenty-nine. He became an Associate Member of this Institution in April 1899, and was also an Associate Member of the Société des Ingénieurs Civils de France from 1896, and a Member of the Société Industrielle du Nord de la France, Lille, from 1895.

William Henry Devine was born in 1844, and educated at the Liverpool Collegiate Institution, and at private academies. From 1875 he was engaged in engineering works in Yokohama and Nagasaki, Japan; and from 1883 was secretary of the Mitsu Bishi Engine Works and Dockyard at Nagasaki, where his death took place on 7th July 1899, at the age of fifty-five. He became an Associate of this Institution in 1896.

John Donaldson was born at Elgin on 29th December 1841. His father and grandfather were owners and managers of all the principal mail coaches in the North of Scotland, and he was educated at the Old Grammar School in Aberdeen. He served an apprenticeship in Morrison's Engineering Works, Ouseburn, Newcastle-on-Tyne, and on

its expiration was engaged for about four years as draughtsman at various works on the north-east coast, and as chief draughtsman at Messrs. Cowans, Sheldon and Co., of Carlisle. He next went to Glasgow University, and distinguished himself highly in examinations. It was in the class-room that he met Mr. John I. Thornycroft, with whom he afterwards went into partnership. Having worked his passage round the Cape of Good Hope as engineer of a small steamer 120 feet long, only to learn that the Egyptian appointment he had in view had been filled, he joined as engineer one of the steamers employed to distil water for Napier's expedition to Abyssinia. On returning to England in 1869, he was appointed chief mechanical engineer at Dum-Dum Arsenal in India, which he completely remodelled. Lord Mayo then transferred him to the Public Works Department, and he reported favourably on the coal and iron in the Hazaribagh district. In 1870 he was appointed chief assistant to the engineer of the Calcutta Port Commissioners, and was engaged in embanking and improving the River Hooghly. In 1872 he married at Bombay the sister of Mr. Thornycroft, who had just started a yard at Chiswick for building high-speed launches. In the following year, having entered into partnership with Mr. Thornycroft, they produced the first fast torpedo-boat, which was for the Norwegian Navy; and by lectures in 1877 and 1881 he helped to bring about their introduction into the British Navy. On the introduction of the Thornycroft water-tube boiler, he induced the Admiralty to allow H.M.S. "Speedy" to be fitted with them, at the sole risk of the makers, and gradually helped to raise the position of the firm until in 1897 they employed 1,800 men. For nine years he gave his experience on the Chiswick Local Board, carrying through an extensive drainage scheme. He was a prime mover in the establishment of the London Association of Engineering Employers, of which he was a vice-president, and for which, when the Employers' Federation was formed, he acted as a representative on the Federation Board and at the conferences. The work entailed by these meetings contributed largely to the breakdown of his health, and his death took place at Pangbourne on 4th October 1899, in his fifty-eight year. He became a Member of this Institution in 1876.

Thomas Constantine Fawcett was born at Armley, near Leeds, on 29th April 1839. Having developed in early youth a strong natural taste for mechanics and engineering, he commenced his career in the works of Sir Peter Fairbairn, Wellington Foundry, Leeds, where he was employed for a few years. Thence he went to complete his apprenticeship with Messrs. Greenwood and Batley, Albion Works, Leeds, where after a few years' service he was made foreman over a department in 1859. In this position he continued for three years until 1862, when he started business for himself as a maker of engineers' tools at Victoria Works, Shannon Street, Leeds. About five years later he took up brick-making machines as a special manufacture, and was highly successful in all kinds of clay-working machinery, particularly for making wire-cut bricks from semi-dry and stiff plastic clay. Of this machinery he made many complete sets, besides many special adaptations to meet peculiar varieties of material; and also various special engines and pumps. In 1886 the concern was removed to the Whitehouse Engineering Works, Hunslet Road, Leeds; and in 1895 was formed into a company, enabling him to leave the management in other hands, and to seek a little well-earned rest after having been in active business for thirty-seven years. He died at his residence, Parkhurst, Chapeltown Road, Leeds, on 27th October 1899, at the age of sixty. He became a Member of this Institution in 1882.

Edward Furness was born in London on 29th September 1843. He served his time for six years in London with Messrs. D. and A. Derrin, engineers, by whom he was afterwards employed to superintend outdoor work, and as a draughtsman. After then spending some time with Messrs. Randolph, Elder and Co., Glasgow, he returned to Messrs. Derrin, to take charge of some work for Sir Henry Bessemer. He was afterwards employed for eight years as head draughtsman and managing engineer with Messrs. H. O. Robinson and Co., sugar machinery engineers, London, for whom he was engaged in designing, carrying out, and reporting upon sugar works, marine work, and general engineering. Then for several years he practised in London as a consulting engineer, designing

sewage pumping engines, sugar machinery, and a good deal of machinery for Bombay and the Cape. About 1882 he became connected with Messrs. Easton and Anderson of Erith; and later with Messrs. Pontifex and Wood in London. On the removal of the works of this firm to Derby in 1893, he resumed private experimental work of his own, and latterly started a business at Gravesend, where through failing health his death took place on 10th October 1899, at the age of fifty-six. He became a Member of this Institution in 1884.

CHARLES RANDOLPH HARVEY was born in Glasgow on 18th December 1846, and received his education at the Glasgow High School. His engineering career commenced in 1864, when he obtained employment with Messrs. Randolph, Elder and Co. About a year after the completion of his apprenticeship he entered the service of Messrs. John Penn and Sons, Greenwich, and later gained additional engineering experience with Messrs. J. and G. Rennie, London. He returned to Glasgow in 1872 to superintend the erection of the late Mr. Randolph's steam road-carriage, and in 1874 joined the firm of Messrs. G. and A. Harvey, machine-tool makers, of Govan. He retired from business through ill-health in June 1898, and his death took place in Glasgow on 12th August 1899, in his fifty-third year. He became a Member of this Institution in 1882.

SAMUEL WILFRED HAUGHTON, the eldest son of Mr. Thomas Haughton, of Kelvin Grove and Greenbank, Carlow, Ireland, was born on 2nd February 1822 at Graigue, a village adjoining Carlow, but in the Queen's County. His early education was received at the Carlow Diocesan School, where he developed a liking for mechanics, and with his cousin and schoolfellow, the late Rev. Dr. Samuel Haughton, F.R.S., Senior Fellow of Trinity College, Dublin (Proceedings 1897, page 514), constructed a model steam-engine, which worked to their satisfaction. From about 1838 to 1845 he served his apprenticeship for seven years to his uncle, Mr. Richard Pim, chief engineer of the Dublin and Kingstown Railway, whom

he succeeded in 1846 as locomotive superintendent, and as chief engineer on his death shortly afterwards. This was the first railway constructed in Ireland, and the second railway opened in the United Kingdom; the opening took place in 1834. On the occasion of the Queen's first visit to Ireland in August 1849, he drove the engine of the royal train from Kingstown to Dublin. On the amalgamation of this line with the Dublin and Wicklow Railway in 1856 he became locomotive superintendent of the joint concern, and also in 1860 of the extension of the line to Wexford. After twenty-six years of railway service he retired in 1864, and lived in Lower Baggot Street, Dublin, with his uncle, Mr. Henry Pim. On his death he returned in 1865 to Greenbank, Carlow, which had descended to him on his father's decease. Here he devoted his energies to the management of the property, including an extent of farm land in County Kildare; and to the welfare of his tenants, among whom were included a considerable number of cottiers in Carlow. For many years he was chairman of the Dispensary Committee, despite the difficulty under which he laboured latterly of increasing deafness. After a very short illness his death took place at Greenbank on 25th March 1898, at the age of seventy-six. He became a Member of this Institution in 1857.

Thomas Kershaw was born at Oldham on 2nd August 1840. After serving his time 1854–56 to Messrs. James Milnes and Co., Oldham, he was employed 1856–61 in the works of Messrs. Asa Lees and Co., machinists, Oldham, and as journeyman fitter 1861–68 at Messrs. Platt's, Hartford Old Works, Oldham. Then for a year and a half he was estimating clerk and draughtsman in a builder's office and works; and afterwards for two years and a half carried on business in Oldham as an architect on his own account. From 1866 he was a student in science classes in Oldham for seven years. From 1868 he was teacher of mechanical science under the Science and Art Department at Manchester, Ashton, Stalybridge, Todmorden, Glodwick and Werneth, Oldham, Elland, and Huddersfield; and in 1869 was selected to superintend teachers' classes in Huddersfield for the Yorkshire Board of Education. From 1886 he was

permanently engaged as head of the engineering department in the Technical School, Huddersfield. His death took place at Huddersfield on 23rd January 1899, at the age of fifty-eight. He became an Associate Member of this Institution in 1893, and of the Society of Architects in 1888.

Benjamin Theophilus Moore was born on 3rd January 1830. Having entered Pembroke College, Cambridge, in 1851, he graduated B.A. in January 1856, and in the same year obtained the place of eighth wrangler in the mathematical tripos. Soon afterwards he was elected to a foundation fellowship of the college, which he retained for some years. In 1856–57 he was mathematical master in the military class at Harrow, and afterwards acted as mathematical master during the illness of the regular master. He next became professor of mathematics for five years at the Staff College, Sandhurst. Afterwards he was occupied in the practice of civil engineering in connection with various engineers of eminence. In 1868 he was appointed professor of civil engineering and applied mechanics in University College, London. Among the books of his authorship was one on mensuration, which was pronounced to stand alone among works on this subject for careful exactness and completeness of mathematical demonstration. He devised a current meter for measuring accurately and rapidly the velocity of a stream of water at any depth (Proceedings Inst. C.E., 1876, vol. xlv. page 220); the instrument was made by Messrs. Troughton and Simms, and was supplied to the Indian government, the conservators of the Thames, and others. The last years of his life were spent in making government ammunition and electric fuses, for the production of which he built two manufactories, one at Dartford in 1880, and the other at Crayford Ness, Erith, in 1889. Among his chief pleasures were the study of astronomy, and working at a fine lathe, at which he was highly expert. His death took place suddenly from heart disease at his residence, Longwood, Bexley, Kent, on 15th November 1899, in the seventieth year of his age. He became a Member of this Institution in 1884, and was also a Member of the Institution of Civil Engineers.

John Smith was born at Rochdale on 31st March 1829. On reaching manhood he entered the employment of Mr. Thomas Robinson, the founder of the firm of Messrs. Thomas Robinson and Son, who had established a saw mill in Water Street, Rochdale, and had procured wood-cutting machinery. At the time of his joining them there as foreman, they had determined to enter upon the construction of wood-working machinery. He proved himself very apt, being possessed of remarkable inventive skill. On their removing to Fishwick Street, and starting there the Railway Works which soon became so extensive, he was raised to the position of manager, and retained this post until his retirement in 1884. A number of valuable inventions which he devised in wood-working appliances were adopted by the firm, and proved highly successful. On the conversion of the concern into a company he became one of the directors, and for some time was its chairman. He was one of the founders of the Rochdale Cotton Spinning Co. in 1884, and a director from the beginning; to him was largely due the great success achieved by this undertaking. While with Messrs. Robinson and Son he travelled much abroad, and the knowledge he thereby gained was of great service. His death took place at his residence, Wintoun Terrace, Drake Street, Rochdale, on 11th July 1899, at the age of seventy. He became a Member of this Institution in 1876.

Charles Edward Stockwell was born at Orange in New South Wales on 19th August 1870, being the eldest son of Mr. Charles Stockwell of Molong in that colony. His early education was received at the Molong Public School, where he developed such talent in mathematics and drawing that at the age of eleven two of his drawings were exhibited in London, for which he gained two medals and a diploma. Afterwards he went to the Sydney Grammar School and Sydney Technical College, and in 1888 passed the Sydney University junior examinations. From December 1889 to December 1893 he served his time as an apprentice in the works of Messrs. Hudson Brothers, engineers, Sydney, four years in the workshops and the fifth in the drawing office, and remained there as assistant draughtsman till April 1896. He was then engaged as

draughtsman by Mr. T. H. Houghton, consulting engineer, Sydney. In February 1898 he was appointed assistant engineer to the Sydney and Suburban Hydraulic Power Co., in whose employ he remained until his untimely death on 18th September 1899 at the age of twenty-nine, which resulted from fracture of the skull caused by his coming into collision with an omnibus whilst riding a bicycle. He became an Associate Member of this Institution in 1897.

DAVID YOUNG was born in Islington, London, on 25th April 1852, of Scottish parentage. On leaving school he was employed from 1867 to 1871 in the office of Mr. James Hosken, consulting engineer, of London. He then served his time from 1871 to 1874 in the works of Mr. George Clark, Southwick Engineering Works, Sunderland, and on its completion he went to sea in 1874 as engineer on the Java vessels of the Commercial Steamship Co. (now known as the Rotterdam Lloyd Steamers), and obtained a first-class certificate as a marine engineer. He was next engaged as draughtsman in the works of Mr. David Rowan, Glasgow, from 1878 to 1879, and in the latter year carried on business in London as patent agent and consulting engineer. In 1881 he was employed by Messrs. Haseltine, Lake and Co., patent agents, of London, as principal assistant and engineer, and in 1891 started again on his own account as patent agent and consulting engineer under the name of D. Young and Co. In 1898 he became a chartered patent agent. While spending a holiday in Lowestoft he met with an accident, and his death resulted on 23rd August 1899, at the age of forty-seven. He became a Member of this Institution in 1889.

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1899.

Parts 3–4.

The Institution of Mechanical Engineers.

ESTABLISHED 1847.

LIST OF PAST-PRESIDENTS

AND OF

OFFICERS FOR 1900.

The Institution of Mechanical Engineers.

PAST-PRESIDENTS.

GEORGE STEPHENSON, 1847–48. (*Deceased* 1848.)

ROBERT STEPHENSON, F.R.S., 1849–53. (*Deceased* 1859.)

SIR WILLIAM FAIRBAIRN, BART., LL.D., F.R.S., 1854–55. (*Deceased* 1874.)

SIR JOSEPH WHITWORTH, BART., D.C.L., LL.D., F.R.S., 1856–57, 1866. (*Deceased* 1887.)

JOHN PENN, F.R.S., 1858–59, 1867–68. (*Deceased* 1878.)

JAMES KENNEDY, 1860. (*Deceased* 1886.)

THE RIGHT HON. LORD ARMSTRONG, C.B., D.C.L., LL.D., F.R.S., 1861–62, 1869.

ROBERT NAPIER, 1863–65. (*Deceased* 1876.)

JOHN RAMSBOTTOM, 1870–71. (*Deceased* 1897.)

SIR WILLIAM SIEMENS, D.C.L., LL.D., F.R.S., 1872–73. (*Deceased* 1883.)

SIR FREDERICK J. BRAMWELL, BART., D.C.L., LL.D., F.R.S., 1874–75.

THOMAS HAWKSLEY, F.R.S., 1876–77. (*Deceased* 1893.)

JOHN ROBINSON, 1878–79.

EDWARD A. COWPER, 1880–81. (*Deceased* 1893.)

PERCY G. B. WESTMACOTT, 1882–83.

SIR LOWTHIAN BELL, BART., F.R.S., 1884.

JEREMIAH HEAD, 1885–86. (*Deceased* 1899.)

SIR EDWARD H. CARBUTT, BART., 1887–88.

CHARLES COCHRANE, 1889. (*Deceased* 1898.)

JOSEPH TOMLINSON, 1890–91. (*Deceased* 1894.)

SIR WILLIAM ANDERSON, K.C.B., D.C.L., F.R.S., 1892–93. (*Deceased* 1898.)

ALEXANDER B. W. KENNEDY, LL.D., F.R.S., 1894–95.

E. WINDSOR RICHARDS, 1896–97.

SAMUEL WAITE JOHNSON, 1898.

The Institution of Mechanical Engineers.

OFFICERS.

1900.

PRESIDENT.

Sir William H. White, K.C.B., LL.D., D.Sc., F.R.S., .. London.

PAST-PRESIDENTS.

The Rt. Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S., Newcastle-on-Tyne.
Sir Lowthian Bell, Bart., F.R.S., ... Northallerton.
Sir Frederick J. Bramwell, Bart., D.C.L., LL.D., F.R.S., London.
Sir Edward H. Carbutt, Bart., ... London.
Samuel Waite Johnson. .... Derby.
Alexander B. W. Kennedy, LL.D., F.R.S., ... London.
E. Windsor Richards, ... Caerleon.
John Robinson, ... Leek.
Percy G. B. Westmacott, ... Ascot.

VICE-PRESIDENTS.

John A. F. Aspinall, ... Manchester.
Arthur Keen, ... Birmingham.
Edward P. Martin, ... Dowlais.
William H. Maw, ... London.
T. Hurry Riches, ... Cardiff.
J. Hartley Wicksteed, ... Leeds.

MEMBERS OF COUNCIL.

Sir William Arrol, M.P., LL.D., ... Glasgow.
Sir Benjamin Baker, K.C.M.G., LL.D., F.R.S., ... London.
Henry Chapman, ... London.
Henry Davey, ... London.
William Dean, ... Swindon.
Bryan Donkin, ... London.
Edward B. Ellington, ... London.
H. Graham Harris, ... London.
Henry A. Ivatt, ... Doncaster.
Henry D. Marshall, ... Gainsborough.
The Right Hon. William J. Pirrie, LL.D., ... Belfast.
Samuel R. Platt, ... Oldham.
Sir Thomas Richardson, M.P., ... Hartlepool.
John I. Thornycroft, F.R.S., ... London.
A. Tannett Walker, ... Leeds.

TREASURER.

Harry Lee Millar.

SECRETARY.

Edgar Worthington,

The Institution of Mechanical Engineers, Storey's Gate, St. James's Park, Westminster, S.W.

Telegraphic address:—*Mech, London.* Telephone:—*Westminster*, 264.

The Institution of Mechanical Engineers.

ESTABLISHED 1847.

LIST OF MEMBERS,

WITH YEAR OF ELECTION.

[*Telegraph Address and Telephone No. appended within brackets.*]

FEBRUARY 1900.

HONORARY LIFE MEMBERS.

1890. H.R.H. Albert Edward, Prince of Wales, K.G., K.T., K.P., G.C.B., G.C.S.I., &c., Marlborough House, Pall Mall, London, S.W.

1899. H.R.H. the Duke of York, K.G., K.T., K.P., &c., York House, St. James's Palace, London, S.W.

1892. Field Marshal H.R.H. the Duke of Cambridge, K.G., K.T., K.P., G.C.B., G.C.S.I., &c., Gloucester House, Park Lane, London, W.

1883. Abel, Sir Frederick Augustus, Bart., K.C.B., D.C.L., D.Sc., F.R.S., The Imperial Institute, Imperial Institute Road, London, S.W.; and 2 Whitehall Court, London, S.W. [*Imperial Institute, London.* Kensington 743.]

1878. Crawford and Balcarres, The Right Hon. the Earl of, K.T., F.R.S., 2 Cavendish Square, London, W.; Haigh Hall, Wigan; and Observatory, Dunecht, Aberdeen.

1889. Eiffel, Gustave, 37 Rue Pasquier, Paris.

1883. Kennedy, Professor Alexander Blackie William, LL.D., F.R.S., 17 Victoria Street, Westminster, S.W. [*Kinematic, London.*]

1878. Rayleigh, The Right Hon. Lord, F.R.S., 4 Carlton Gardens, London, S.W.; and Terling Place, Witham, Essex.

1897. Roberts-Austen, Sir William Chandler, K.C.B., D.C.L., F.R.S., Professor of Metallurgy, Royal College of Science; Chemist of the Royal Mint, Tower Hill, London, E.

1888. Rosse, The Right Hon. the Earl of, K.P., D.C.L., LL.D., F.R.S., Birr Castle, Parsonstown, Ireland.

1896. Unwin, William Cawthorne, F.R.S., Professor of Engineering, City and Guilds of London Central Institution, Exhibition Road, London, S.W.; and 7 Palace Gate Mansions, Kensington, London, W.

MEMBERS.

1890. Abbott, Arthur Harold, care of Messrs. Octavius Steel and Co., Calcutta, India.

1878. Abbott, Thomas, Newark Boiler Works, Newark [*Abbott, Newark.*]; and The Square, Retford.

1861. Abel, Charles Denton, Messrs. Abel and Imray, Birkbeck Bank Chambers, Southampton Buildings, London, W.C. [*Patentable, London.* Holborn 109.]

1894. Accles, William Sloane, 39 Victoria Street, Westminster, S.W.

1892. Acland, Captain Francis Edward Dyke, 76 Cheapside, London, E.C. [*Onager, London.* Bank 5252.]

1897. Adams, Edwin, Messrs. Hulse and Co., Ordsal Works, Regent Bridge, Salford, Manchester.

1876. Adams, Henry, 60 Queen Victoria Street, London, E.C. [*Viburnum, London.*]

1881. Adams, William John, 35 Queen Victoria Street, London, E.C. [*Packing, London.* Bank 38.]

1900. Adamson, Charles John, 4 South Street, Greenwich, London, S.E.

1897. Adamson, Daniel, Works Manager, Messrs. Joseph Adamson and Co., Hyde, near Manchester.

1871. Adamson, Joseph, Messrs. Joseph Adamson and Co., Hyde, near Manchester. [*Adamson, Hyde.*]

1889. Addy, George, Waverley Works, Sheffield. [*Milling, Sheffield.* 985.]

1887. Ahmed Pasha, Rear Admiral, Engineer-in-Chief and Head of Technical Inspecting Commission, Imperial Naval Arsenal, Constantinople.

1891. Ahrbecker, Henry Conrad Vandepoel, Mort's Dock and Engineering Co., Balmain, Sydney, New South Wales.

1895. Ahrons, Ernest Leopold, Messrs. Simon-Carves, 20 Mount Street, Manchester.

1893. Ainley, Henry, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1900. Aiton, John Arthur, Messrs. Clark and Aiton, 25 Laurence Pountney Lane, London, E.C. [*Channeled, London.* Bank 5837.]

1898. Akers, Charles Henry, 16 Calle Oriente, No. 35, Guatemala.

1885. Alderson, George Beeton, Messrs. Allen, Alderson and Co., Alexandria, Egypt; Norland House, Ramleh, Alexandria, Egypt: (or care of Messrs. Stafford Allen and Sons, 7 Cowper Street, Finsbury, London, E.C.)

1881. Alexander, Edward Disney, Milton, Northamptonshire.

1875. Allan, George, 28 Victoria Street, Westminster, S.W.

1898. Allan, Robert, Messrs. Riley, Hargreaves and Co., Singapore, Straits Settlements: (or care of David Dunlop, 93 Hope Street, Glasgow.)

1885. Allcard, Harry, Messrs. Easterbrook Allcard and Co., Albert Works, Penistone Road, Sheffield.

1874. Allen, Francis, Messrs. Allen Alderson and Co., Gracechurch Street, Alexandria, Egypt: (or care of Messrs. Stafford Allen and Sons, 7 Cowper Street, Finsbury, London, E.C.)

1891. Allen, Marcus, Union Brass and Iron Works, Great Ancoats Street, and Phœnix Iron Works, Jersey Street, Manchester [*Valves, Manchester. Nat.* 60.]; and The Nest, Knutsford.

1881. Allen, Percy Ruskin, Castner-Kellner Alkali Co., Weston Point, Runcorn; and Ferncliffe, Higher Runcorn, Cheshire.

1885. Allen, William Henry, Messrs. W. H. Allen Son and Co., York Street Works, Lambeth, London, S.E. [*Pump, London.*]; and Queen's Engineering Works, Bedford. [*Pump, Bedford.*]

1882. Allen, William Milward, Principal Assistant Engineer, Engine Boiler and Employers' Liability Insurance Co., 12 King Street, Manchester.

1899. Alley, Stephen Evans, Manager, Messrs. Alley and MacLellan, Sentinel Works, Polmadie Road, Glasgow. [*Alley, Glasgow.* Royal 673.]

1865. Alleyne, Sir John Gay Newton, Bart., Chevin, Belper.

1884. Alleyne, Reynold Henry Newton, North Wootton, King's Lynn.

1872. Alliott, James Bingham, Messrs. Manlove Alliott and Co., Bloomsgrove Works, Ilkeston Road, Nottingham. [*Manloves, Nottingham.*]

1891. Allott, Charles Sneath, 46 Brown Street, Manchester. [*Allotted, Manchester. Nat.* 1952.]

1871. Allport, Howard Aston, Dodworth Grove, Barnsley.

1884. Almond, Harry John, General Manager, La Guaira and Caracas Railway, Caracas, Venezuela: (or care of Messrs. G. and W. Almond, 67 Willow Walk, London, S.E.)

1885. Amos, Ewart Charles, Mansion House Chambers, 11 Queen Victoria Street, London, E.C.; and Eastdene, St. James' Road, Sutton, Surrey. [*Drilling, London.*]

1867. Amos, James Chapman, Rose Cottage, Fairfax Road, Teddington, S.O., Middlesex.

1891. Anderson, Alexander Southerland, Chief Engineer, Ordnance Department, Ordnance Factory, Cawnpore, India.

1880. Anderson, Edward William, Lesney, Warwick Road, Solihull, Birmingham.

1890. Anderson, Herbert William, Messrs. Hilton Anderson and Co., Manor Works, Halling, near Rochester.

1892. Anderson, John Wemyss, Pearl Assurance Buildings, Liverpool. [*Thermo, Liverpool. Nat.* 7461.]

1894. Anderson, Tom Scott, Royal Insurance Buildings, Sheffield; and 8 Southbourne Road, Victoria Park, Sheffield.

1891. Anderson, William, Messrs. Head Wrightson and Co., Teesdale Iron Works, Stockton-on-Tees.

1899. Andrew, George Edward, Engineer, R.N., H.M.S. "Resolution," Gibraltar.

1892. Andrew, Thomas, Rand Club, Johannesburg, Transvaal, South Africa.

1895. Andrews, Thomas, Messrs. Andrews and Baby, Welsh Wagon Works, East Moors, Cardiff. [*Wagons, Cardiff.* 693.]

1893. Angas, William Moore, Jacksonville, Florida, United States: (or care of G. Douglas Angas, Neswick, Bainton, Hull.)

1885. Anson, Frederick Henry, 15 Dean's Yard, Westminster, S.W.

1899. Appleby, George William, Revenue Cruiser "Likin," care of Imperial Maritime Customs, Kowloon, Hong Kong, China.

1883. Appleby, Percy Vavasseur, London Steam Crane and Engine Works, Grafton Place, Leicester.

1874. Aramburu y Silva, Fernando, Almagro 32, Madrid.

1881. Archbold, Joseph Gibson, Manager, Blyth Dry Dock, Blyth, Northumberland.

1874. Archer, David, 275 Pershore Road, Birmingham.

1883. Arens, Henrique, Messrs. Arens and Irmaos, Engineering Works, Rio de Janeiro, Brazil: (or care of Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.)

1882. Armer, James, Messrs. John Birch and Co., 11 Queen Street Place, London, E.C.

1894. Armour, James Glencairn, Cereal Court (A), Brunswick Street, Liverpool.

1858. Armstrong, The Right Hon. Lord, C.B., D.C.L., LL.D., F.R.S., Elswick, Newcastle-on-Tyne; and Cragside, Morpeth.

1866. Armstrong, George, Locomotive Department, Great Western Railway, Stafford Road Works, Wolverhampton.

1882. Armstrong, George Frederick, F.R.S.E., Professor of Engineering, The University, Edinburgh.

1876. Armstrong, William, Jun., Mining Engineer, Wingate Colliery, County Durham.

1870. Armstrong, William Irving, Timber Works and Saw Mills, 17 North Bridge Street, Sunderland.

1898. Arnold, Joseph Albert, Messrs. Eastwood, Swingler and Co., Victoria and Railway Iron Works, Derby. [*Swingler, Derby.* 150.]

1894. Arnot, William, 79 West Regent Street, Glasgow. [*Induction, Glasgow.* 5341.]

1887. Arrol, Sir William, M.P., LL.D., Dalmarnock Iron Works, Glasgow.

1887. Arteaga, Alberto de, 1320 Artes, Buenos Aires, Argentine Republic: (or care of M. Raggio-Carneiro, 55 and 56 Bishopsgate Street Within, London, E C.)

1873. Ashbury, Thomas (*Life Member*), 17 St. Ann's Square, Manchester; and Ash Grove, Victoria Park, Longsight, Manchester. [*Thomas Ashbury, Manchester.*]

1888. Ashby, George, Messrs. N. Wadia and Sons, Cumballa Hill, Bombay, India.

1895. Ashcroft, Andrew George, City and Guilds of London Central Institution, Exhibition Road, London, S.W.; and 1 Gainsborough Road, Bedford Park, London, W.

1890. Ashley, Thomas James, Messrs. McNeill and Co., Samarang, Java.

1891. Ashworth, Henry, The Villa, Llangorse, Talgarth, R.S.O., Breconshire.

1890. Askham, John Unwin, Messrs. Askham Brothers and Wilson, Yorkshire Steel Works, Napier Street, Sheffield.

1890. Askham, Philip Unwin, Messrs. Askham Brothers and Wilson, Yorkshire Steel Works, Napier Street, Sheffield.

1881. Aspinall, John Audley Frederick, General Manager, Lancashire and Yorkshire Railway, Hunt's Bank, Manchester; and Gledhill, Mossley Hill Drive, Liverpool.

1891. Asplen, Bernard, Southall: (or care of W. W. Asplen, Foxton Hall, Royston, Cambridgeshire.)

1877. Astbury, James, Smethwick Foundry, near Birmingham.

1890. Aston, John W., Messrs. G. E. Belliss and Co., Ledsam Street, Birmingham; and Municipal Technical School, Birmingham.

1899. Atherton, Thomas, Dallam Forge, Warrington; and Folly Lane, Warrington.

1875. Atkinson, Edward (*Life Member*), 32 Park Road, West Dulwich, London, S.E.

1890. Atkinson, Edward Turner, London County Council, Spring Gardens, London, S.W.

1892. Atkinson, James, The Woodlands, Marple, near Stockport.

1897. Atsumi, Sadamoto, 26 Nishino-cho, Unagitani, Osaka, Japan.

1898. Attwood, Jabez, Foster Street, Stourbridge. [*Attwoods, Stourbridge.*]

1892. Ault, Edwin, 47 Victoria Street, Westminster, S.W.

1892. Austin, James Meredith, 11 Emperor's Gate, London, S.W.

1894. Aveline, William Rebotier, Shell Transport and Trading Co., 16 Leadenhall Street, London, E.C.

1882. Aveling, Thomas Lake, Messrs. Aveling and Porter, Rochester. [*Aveling, Rochester.*]

1897. Avery, William Beilby (*Life Member*), Messrs. W. and T. Avery, Soho Foundry and Digbeth, Birmingham; and Oakley Court, Windsor.

1899. Awdry, Walter Llewellyn, 39 Corporation Street, Birmingham. [1806.]

1891. Bagshaw, Walter, Victoria Foundry, Batley.

1899. Baguley, Ernest Edwin, Manager, Messrs. W. G. Bagnall, Castle Engine Works, Stafford.

1885. Bailey, Sir William Henry, Albion Works, Salford, Manchester [*Beacon, Salford.*]; and Sale Hall, Cheshire.

1899. Bailey, William Seybourne, 17 Praya Central, Hong Kong, China

1872. Bailly, Philimond, 282 Rue Royale, Bruxelles, Belgium.

1890. Bain, George, Locomotive Department, Egyptian Government Railways, Cairo, Egypt.

1880. Bain, William Neish, 40 St. Enoch Square, Glasgow; and Collingwood, 7 Aytoun Road, Pollokshields, Glasgow. [*Glacis, Glasgow.*]

1869. Bainbridge, Emerson, M.P., Nunnery Colliery Offices, New Haymarket, Sheffield; and 4 Whitehall Court, London, S.W.

1898. Baister, Charles, Locomotive Engineer, North Eastern Railway, Darlington.

1890. Baker, Sir Benjamin, K.C.M.G., LL.D., F.R.S. (*Life Member*), 2 Queen Square Place, Westminster, S.W.

1897. Baker, George Samuel, Messrs. Joseph Baker and Sons, Willesden Junction, London, N.W. [*Mapleleaf, London.* Harlesden 3.]

1896. Baker, William Henry, Superintendent of Works, Residency Post Office, Gwalior, Central India.

1893. Baldwin, Alfred, M.P., Wilden Iron Works, Stourport.

1894. Baldwin, Arthur Hugh, Messrs. Kendall and Gent, Victoria Works, Belle Vue, Manchester. [*Tools, Manchester.* 5147.]

1877. Bale, Manfred Powis, Appold Street, Finsbury, London, E.C.

1897. Balkwill, Alfred John, Works Manager, Messrs. E. Green and Son, Economiser Works, Wakefield.

1898. Bamford, Robert George, Perambore Works, Madras Railway, Madras, India.

1887. Bamlett, Adam Carlisle, Agricultural Engineering Works, Thirsk.

1898. Bancroft, Francis James, Water Engineer, Town Hall, Hull.

1892. Banister, George Henry, Carriage Department, Royal Arsenal, Woolwich.

1899. Banks, George, Assistant Carriage and Wagon Superintendent, Lancashire and Yorkshire Railway, Newton Heath, Manchester; and Montford, Altrincham.

1888. Barker, Eric Gordon, Locomotive Superintendent, Wirral Railway, Dock Station, Birkenhead; and Guyse House, Oxton, R.O., near Birkenhead.

1899. Barker, Gerald, 1 Victoria Street, Westminster, S.W.

1896. Barker, Matthew Wilson, 110 Stapleton Hall Road, Stroud Green, London, N.

1885. Barker, Tom Birkett, Westfield, Knowle, Warwickshire.

1899. Barley, Clement Johnson, 87 Cambridge Street, St. George's Road, London, S.W.

1880. Barlow-Massicks, Thomas, The Oaks, Millom, Cumberland.

1891. Barnes, John Edward Lloyd, Messrs. Sloan and Lloyd Barnes, 34 Castle Street, Liverpool. [*Technical, Liverpool.* 6080.]

1881. Barnett, John Davis, Assistant Mechanical Superintendent, Grand Trunk Railway, Stratford, Ontario, Canada.

1887. Barningham, James, 41 Victoria Buildings, Victoria Street, Manchester.
1884. Barr, Archibald, D.Sc., Professor of Engineering, The University, Glasgow.
1887. Barringer, Herbert, 88 Bishopsgate Street Within, London, E.C.
1862. Barrow, Joseph, Messrs. Thomas Shanks and Co., Johnstone, near Glasgow. [*Shanks, Johnstone.*]
1871. Barry, Sir John Wolfe, K.C.B., LL.D., F.R.S., 21 Delahay Street, Westminster, S.W. [*Consilium, London.* Westminster 24.]
1883. Bartlett, James Herbert, Middlesbrough, Kentucky, United States.
1899. Bashforth, Andrew, Messrs. Steel, Peech and Tozer, Phœnix Special Steel Works, The Ickles, Sheffield; and Fern Lea, Gerard Road, Rotherham.
1887. Bate, Major Charles McGuire, R.E., Royal Engineers' Office, Ryde, Isle of Wight.
1885. Bateman, Henry, Superintendent, Municipal Fire Brigade and Stores, Rangoon, India.
1896. Bateman, James Thomas, Fair View, Bebington, near Birkenhead.
1891. Bates, Henry, Messrs. Hulse and Co., Ordsal Works, Regent Bridge, Salford, Manchester; and 30 Halliwell Terrace, Trafford Road, Salford, Manchester.
1892. Baxter, Peter Macleod, Messrs. McKie and Baxter, Copland Works, Govan, Glasgow.
1889. Bayford, William James, 34 Westmoreland Road, Bayswater, London, W.
1899. Bayley, George Ridley, Resident Engineer and Manager, Liverpool Hydraulic Power Co., 123 Athol Street, Liverpool, N.
1872. Bayliss, Thomas Richard, Belmont, Northfield, Birmingham.
1891. Baynes, John, Electric Railway Carriage and Tramway Works Co., Strand Road, Preston, Lancashire.
1899. Beale, Bertram Robert, Managing Director, The Fownes Forge and Engineering Co., 37 Lime Street, London, E.C. [*Ultroneus, London.* Avenue 1874.]
1898. Beard, Arthur Charles, London County Council, Spring Gardens, London, S.W.
1895. Beard, Bernard, 53 Island Road, Garston, near Liverpool.
1887. Beardmore, William, Parkhead Forge and Steel Works, Glasgow.
1893. Beare, Thomas Hudson, F.R.S.E., Professor of Engineering, University College, Gower Street, London, W.C.
1891. Beatty, Hazlitt Michael, Chief Locomotive Superintendent, Cape Government Railways, Cape Town, Cape Colony; and Rosclare Camp Ground, Rondebosch, near Cape Town, Cape Colony.
1899. Beaumont, Roberts, Professor of Textile Industries, Yorkshire College, Leeds.

1880. Beaumont, William Worby, Outer Temple, 222 Strand, London, W.C. [*Vibromotor, London.*]

1859. Beck, Edward (*Life Member*), Dallam Forge, Warrington; and Springfield, Warrington.

1873. Beck, William Henry, 115 Cannon Street, London, E.C.

1882. Bedson, Joseph Phillips, Newton House, Hyde, near Manchester.

1875. Beeley, Thomas, Messrs. Thomas Beeley and Son, Hyde Junction Iron Works, Hyde, near Manchester. [*Beeley, Hyde.*]

1899. Beeley, Thomas Carter, Messrs. Thomas Beeley and Son, Hyde Junction Iron Works, Hyde, near Manchester. [*Beeley, Hyde.*]

1898. Beesly, Gerald, Managing Director, Tubes Co., Credenda Works, Bridge Street, Smethwick, Birmingham; and 14 Frederick Road, Edgbaston, Birmingham.

1888. Beldam, Asplan, 77 Gracechurch Street, London, E.C.

1885. Bell, Charles Lowthian, Clarence Iron Works, Middlesbrough; and Linthorpe, Middlesbrough. [*Bells, Middlesbrough.* 5510.]

1897. Bell, Captain Charles Thornhill, R.A., Superintendent, Gun Carriage Factory, Madras, India.

1858. Bell, Sir Lowthian, Bart., F.R.S., Clarence Iron Works, Middlesbrough; Rounton Grange, Northallerton; and Reform Club, Pall Mall, London, S.W. [*Sir Lowthian Bell, Middlesbrough.*]

1897. Bellamy, Alfred Rowe, Managing Director, Messrs. J. E. H. Andrew and Co., Reddish, near Stockport.

1868. Belliss, George Edward, Messrs. Belliss and Morcom, Ledsam Street, Birmingham [*Belliss, Birmingham.*]; and The Dell, King's Norton, near Birmingham.

1897. Belliss, John, Messrs. Belliss and Morcom, Ledsam Street, Birmingham. [*Belliss, Birmingham.*]

1878. Belsham, Maurice, Messrs. Price and Belsham, 52 Queen Victoria Street, London, E.C.

1895. Benn, Sykes, Messrs. S. S. Stott and Co., Haslingden, near Manchester. [*Elevator, Haslingden.* 103.]

1894. Bennett, James William, Messrs. Taylor and Lawson, Engineering Works, Batavia; and Harwood, Branksome Park, Bournemouth.

1900. Bennie, Peter, Agencia de Tharsis, Huelva, Spain.

1895. Bennington, John William, Fleet Engineer, R.N., H.M.S. "Hermione," China.

1895. Bennion, Charles, Messrs. Pearson and Bennion, Union Works, Leicester; and Danes Hill House, Hinckley Road, Leicester. [*Prominent, Leicester.* 103.]

1895. Bennis, Alfred William, Messrs. E. Bennis and Co., 28 Victoria Street, Westminster, S.W.

1894. Bentley, George, Messrs. Bentley and Jackson, Lodge Bank Works, Bury, Lancashire.

1895. Berchem, Alphonse Henry Emanuel, Worthington Pumping Engine Co., 153 Queen Victoria Street, London, E.C.

1878. Berrier-Fontaine, Marc, Directeur des Constructions navales, Directeur de l'Établissement national d'Indret, par la Basse Indre, (Loire inférieure), France.

1893. Berry, Henry, Croydon Works, Leeds.

1893. Berry, John Ferrier, care of Messrs. Howard Farrar and Co., P. O. Box 455, Johannesburg, Transvaal, South Africa.

1897. Berthiez, Charles, Messrs. de Fries and Co., Düsseldorf, Germany.

1891. Bertram, David Noble, Messrs. Bertrams, St. Katherine's Works, Sciennes, Edinburgh.

1891. Best, Francis Edward, 1 Swan Walk, Chelsea Embankment, London, S.W.

1899. Beswick, Frederick Arrowsmith, Manchester Steam Users' Association, 9 Mount Street, Manchester.

1893. Betts, Samuel, Locomotive Superintendent, Oxelösund-Fleu-Westmanlands Railway, Eskilstuna, Sweden.

1891. Bevis, Alfred William, Brunswick Villa, Malvern Road, Acock's Green, Birmingham.

1866. Bevis, Restel Ratsey, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead; and Manor Hill, Birkenhead.

1885. Bicknell, Arthur Channing, 42 Pelham Street, South Kensington, London, S.W.

1884. Bika, Léon Joseph, Locomotive Engineer-in-Chief, Belgian State Railway, 29 Rue des Palais, Bruxelles, Belgium.

1898. Bilbie, John, Messrs. Bilbie, Hobson and Co., 80 Queen Victoria Street, London, E.C.

1899. Biles, John Harvard, Professor of Naval Architecture, The University, Glasgow.

1897. Billetop, Torben Christian, Messrs. Henry Watson and Son, High Bridge Works, Newcastle-on-Tyne.

1888. Billinton, Robert John, Locomotive Superintendent, London Brighton and South Coast Railway, Brighton.

1890. Bingham, Charles Henry, Messrs. Walker and Hall, Electro Works, Howard Street, Sheffield. [*Bingham, Sheffield.*]

1887. Binnie, Sir Alexander Richardson, Engineer, London County Council, Spring Gardens, London, S.W.; and 77 Ladbroke Grove, Notting Hill, London, W.

1891. Bird, George, Messrs. James Bartle and Co., Western Iron Works, Notting Hill, London, W.

1897. Bird, William Hobart, Hearsall House, Coventry.

1880. Birkett, Herbert, 91 Victoria Street, Westminster, S.W.

1896. Black, Peter Blair, 185 Palmerston Buildings, Old Broad Street, London, E.C. [*Blackness, London.*]

1879. Black, William, 1 Lovaine Place, Newcastle-on-Tyne.

1891. Blackburn, Arthur Henry, Fuel Economizer Co., Matteawan, New York, United States.

1891. Blackburn, George William, Messrs. T. Green and Son, Smithfield Iron Works, Leeds.

1890. Blackburn, John, Resident Engineer, Colne Valley Water Works, Bushey, Watford.

1898. Blackstone, Edward Christopher, Managing Director, Messrs. Blackstone and Co., Rutland Engineering Works, Stamford. [*Blackstones, Stamford.*]

1898. Blane, William, P.O. Box 435, Johannesburg, Transvaal, South Africa.

1895. Blaxter, Augustus Pearce, Jun., Messrs. Barnett and Foster, Niagara Works, Eagle Wharf Road, New North Road, London, N.

1892. Blechynden, John, General Manager, Shanghai Engineering, Shipbuilding and Dock Company, Shanghai, China. [*Steam, Shanghai.*]

1867. Bleckly, John James, Bewsey Iron Works, Warrington; and Daresbury Lodge, Altrincham.

1899. Blenkinsop, John Nicholas, Marine Superintendent Engineer, Great Eastern Railway, Parkeston Quay, Harwich.

1882. Blundstone, Samuel Richardson, Catherine Chambers, 8 Catherine Street, Strand, London, W.C.

1884. Bocquet, Harry Claude, Leopoldina Railway, Rio de Janeiro, Brazil: (or Llanwye, Hampton Park, Hereford.)

1863. Boeddinghaus, Julius, Electrotechniker, Düsseldorf, Germany.

1898. Boffey, William, Messrs. Green and Co., Church Gresley Potteries, near Burton-on-Trent.

1895. Bond, George Creswell, Newcastle Chambers, Nottingham. [*Bonds, Nottingham.* 441.]

1884. Bone, William Lockhart, Works of the Ant and Bee, West Gorton, Manchester.

1895. Boorman, Joseph Ashworth, Messrs. Greenwood and Batley, Albion Works, Leeds.

1892. Booth, John William, Union Foundry, Rodley, near Leeds.

1890. Booth, Robert, 110 Cannon Street, London, E.C.

1888. Borrows, William, Messrs. Edward Borrows and Sons, Providence Foundry, Sutton, St. Helens, Lancashire.

1891. Boswell, Samuel, Messrs. Galloways, Knott Mill Iron Works, Manchester; and 2 Wentworth Villas, Clarence Road, Longsight, Manchester.

1899. Bottomley, John William, Messrs. Thomas C. Fawcett and Co., White House Engineering Works, Leeds.

1888. Boulding, Sidney, Messrs. Green and Boulding, 105 Bunhill Row, London, E.C. [*Temperature, London.*]

1886. Boult, Alfred Julius, Messrs. Boult, Wade and Kilburn, 111 Hatton Garden, London, E.C. [*Boult, London.* Holborn 180.]

1878. Bourdon, François Edouard, 74 Faubourg du Temple, Paris: (or care of Messrs. Negretti and Zambra, Holborn Viaduct, London, E.C.)

1886. Bourne, Thomas Johnstone, Imperial Chinese Railways, Tientsin, China: (or care of Mrs. Bourne, 16 Park Road, Southborough, Tunbridge Wells.)

1879. Bourne, William Temple, Messrs. Bourne and Grove, Bridge Steam Saw Mills, Worcester.

1891. Bousfield, John Ebenezer, 4 South Street, Finsbury, London, E.C. [*Invention, London.* Avenue 691.]

1880. Bow, William, Messrs. Bow McLachlan and Co., Thistle Engine Works, Paisley. [*Bow, Paisley.*]

1888. Bowen, Edward (*Life Member*), Locomotive and Carriage Superintendent, Porto Alegre and New Hamburg Railway, Rio Grande do Sol, Brazil: (or care of Benjamin Packham, 18 Upper Wellington Road, Brighton.)

1858. Bower, John Wilkes (*Life Member*), Meredale, Rugby Road, Leamington Spa.

1892. Bowker, Arthur F., Ightham, Kent.

1899. Bowler, Thomas, Works Manager, Messrs. Kitson and Co., Airedale Foundry, Leeds.

1899. Bowman, Harold, Messrs. Stevenson and Co., Canal Foundry, Preston. [*Stevenson, Preston.*]

1893. Boyd, James Tennant, Lochgarry Lodge, Lenzie, Glasgow.

1890. Boyd, John White, 59 St. Vincent Street, Glasgow. [*Silent, Glasgow.*]

1882. Bradley, Frederic, Sandhills, Liverpool; Clensmore Foundry, Kidderminster; and Thornton Hall, Childer Thornton, near Chester.

1897. Bradley, James William, Town Hall, Wolverhampton.

1896. Bradney, Walter, Billiter Buildings, Billiter Street, London, E.C.

1897. Bradshaw, George Theobald Mathew, Locomotive and Resident Engineer, Ballycastle Railway, Ballymoney, Ireland.

1878. Braithwaite, Charles C., Boreham Wood Works, Elstree, Herts. [*Packing, Boreham Wood.*]

1875. Braithwaite, Richard Charles, Messrs. Braithwaite and Kirk, Crown Bridge Works, Westbromwich [*Braithwaite, Westbromwich.*]; and 39 Victoria Street, Westminster, S.W.

1900. Bramsdon, William Henry, Fleet Engineer R.N., H.M.S. "Ramillies," Mediterranean Squadron.

1854. Bramwell, Sir Frederick Joseph, Bart., D.C.L., LL.D., F.R.S., Messrs. Bramwell and Harris, 5 Great George Street, Westminster, S.W. [*Wellbram, London.* Westminster 60.]

1895. Bratt, Edward Hicks Fraser, Messrs. Bratt and Gibson, Taiping, Perak, Straits Settlements.

1885. Brearley, Benjamin J., Union Plate Glass Works, St. Helens; and Ansdell Road, Rainhill, Lancashire.

1900. Brearley, Frederick Thomas, Union Plate Glass Co., Pocket Nook, St. Helens.

1891. Brewster, Edwin Henry George, 12 Dartmouth Street, Queen Anne's Gate, Westminster, S.W.

1890. Brewster, Walter Seckford, Wrentham, Fleet Street, Carlton, near Sydney, New South Wales.

1887. Brier, Henry, Messrs. J. and E. Hall, Dartford; and 1 Miskin Road, Dartford.

1889. Briggs, Charles, care of Robert Briggs, Howden.

1881. Briggs, John Henry, Babcock and Wilcox Boiler Works, Renfrew.

1895. Britten, Thomas Johnson, P.O. Box 494, Johannesburg, Transvaal, South Africa.

1891. Broadbent, William, Messrs. Thomas Broadbent and Sons, Central Iron Works, Huddersfield. [*Broadbent, Huddersfield.* 102.]

1896. Broadfoot, Andrew Wilson, Locomotive Superintendent, Great Southern Railway, Albany, Western Australia.

1891. Brock, Cameron William Harrison, 30 Fox Hill, Upper Norwood, London, S.E.

1865. Brock, Walter, Messrs. Denny and Co., Engine Works, Dumbarton. [*Lennox, Dumbarton.* 1 and 15.]

1896. Brocklehurst, George, Bridgetown, Barbados, West Indies.

1890. Brodie, John Alexander, City Engineer, Municipal Buildings, Liverpool.

1897. Brodrick, William Holborn, 37 Wellington Street, Hull.

1852. Brogden, Henry (*Life Member*), Hale Lodge, Altrincham, near Manchester.

1890. Brogden, Thomas, Messrs. Appleby and Brogden, Sandside, Scarborough.

1892. Bromiley, William J., Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton.

1892. Bromly, Alfred Hammond, 18 Eldon Street, Moorfields, London, E.C.

1892. Brooke, John Walter, Adrian Iron Works, Lowestoft.

1892. Brooke, Robert Grundy, Messrs. Holden and Brooke, Sirius Works, West Gorton, Manchester. [*Influx, Manchester.*]

1884. Brook-Fox, Frederick George, Messrs. Grindlay and Co., 55 Parliament Street, Westminster, S.W.

1897. Brooks, Samuel Herbert (*Life Member*), Union Iron Works, West Gorton, Manchester.

1880. Brophy, Michael Mary, Messrs. James Slater and Co., 251 High Holborn, London, W.C.

1874. Brotherhood, Peter, 15 and 17 Belvedere Road, Lambeth, London, S.E.; and 15 Hyde Park Gardens, London, W. [*Brotherhood, London.*]

1886. Brown, Andrew, 110 Cannon Street, London, E.C.; and Willis Road, Erith, S.O., Kent. [*Browpost, London.* Bank 647.]

1866. Brown, Andrew Betts, F.R.S.E., Messrs. Brown Brothers and Co., Rosebank Iron Works, Edinburgh.

1891. Brown, Arthur Mogg, 128 West Parade, Lincoln.

1885. Brown, Benjamin, Widnes Foundry, Widnes.

1880. Brown, Francis Robert Fountaine, St. James' Club, Montreal, Canada.

1889. Brown, Captain Frederick Alexander William, R.A., Army Ordnance Department, Haulbowline, Cork Harbour, Ireland.

1881. Brown, George William, Trollhättan, Alexandra Road, Reading. [251.]

1898. Brown, Harry, Department of Mines, Sydney, New South Wales.

1892. Brown, James Fiddes, Works Superintendent, Charing Cross and Strand Electricity Supply Corporation, 15 Maiden Lane, Strand, London, W.C.

1884. Brown, Oswald, 32 Victoria Street, Westminster, S.W. [*Acqua, London.*]

1888. Brown, William, Messrs. W. Simons and Co., London Works, Renfrew.

1892. Brown, William, Messrs. Siemens Brothers and Co., Woolwich.

1874. Browne, Tomyns Reginald, Deputy Locomotive Superintendent, East Indian Railway, Howrah, Bengal, India: (or care of Messrs. W. Watson and Co., 7 Waterloo Place, Pall Mall, London, S.W.)

1874. Bruce, Sir George Barclay, 3 Victoria Street, Westminster, S.W.

1899. Bruce, Graham Stewart, Deputy Locomotive and Carriage Superintendent, South Indian Railway, Negapatam, India.

1889. Bruce, Robert, 77 Billiter Buildings, London, E.C. [*Tangential, London.*]

1867. Bruce, William Duff, 17 Victoria Street, Westminster, S.W.; and 23 Roland Gardens, South Kensington, London, S.W.

1873. Brunel, Henry Marc, 21 Delahay Street, Westminster, S.W. [Westminster 24.]

1892. Brunlees, John, 12 Victoria Street, Westminster, S.W. [Westminster 245.]

1887. Brunton, Philip George, Inspector of Ironwork, Public Works Department, Sydney, New South Wales: (or care of J. D. Brunton, 19 Great George Street, Westminster, S.W.)

1884. Bryan, William B., Engineer, East London Water Works, Lea Bridge, Clapton, London, N.E.

1899. Buchanan, James, Messrs. James Buchanan and Son, Caledonia Foundry and Engine Works, Brasenose Road, Liverpool. [*Buchanan, Liverpool.* Bootle 132.]

1892. Buckley, John T., 36 Cleveland Road, Lytham, R.S.O., Lancashire.

1895. Buckley, Victor Emanuel, Managing Director, Riga Spinning and Thread Works, Strasdenhof, Riga, Russia.

1886. Buckney, Thomas, 53 Gower Street, London, W.C.

1887. Buckton, Walter, 27 Ladbroke Square, London, W.

1896. Buckwell, George William, Board of Trade Offices, Sunderland.

1878. Buddicom, Harry William, Penbedw, Nannerch, near Mold.

1886. Budenberg, Christian Frederick, Messrs. Schäffer and Budenberg, Whitworth Street, London Road, Manchester; and Somerville, Arkwright Road, Marple, Stockport. [*Manometer, Manchester.* 899.]

1882. Budge, Enrique, Engineer-in-Chief, Harbour Works, Valparaiso, Chile: (or care of Messrs. Rose-Innes Cox and Co., 4 Fenchurch Avenue, London, E.C.)

1881. Bulkley, Henry Wheeler, N.Y. Times Building, 41 Park Row, New York, United States.

1884. Bullock, Joseph Howell, General Manager, Pelsall Coal and Iron Works, near Walsall; and The Laburnums, Hill Top, West Bromwich.

1882. Bulmer, John, Spring Garden Engineering Works, Pitt Street, Newcastle-on-Tyne.

1891. Bumsted, Francis Dixon, Cannock Chase Foundry and Engine Works, Hednesford, near Stafford.

1884. Bunt, Thomas, Superintendent Engineer, Kiangnan Arsenal, Shanghai, China: (or care of R. Pearce, Lanarth House, Holders Hill, Hendon, London, N.W.)

1899. Burcham, Richard Edward, Manchester Steam Users' Association, 9 Mount Street, Manchester; and Richmond Terrace, Vine Street, Openshaw, Manchester.

1885. Burder, Walter Chapman, Messrs. Messenger and Co., Loughborough.

1891. Burgess, Francis Chassereau Boughey, Locomotive Superintendent, Lagos Railway, Lagos, West Coast Africa: (or care of Messrs. William Watson and Co., 7 Waterloo Place, London, S.W.)

1894. Burke, Michael James, Locomotive and Carriage Superintendent, Morvi Railway, Morvi, India.

1881. Burn, Robert Scott, 11 Albert Terrace, Musselburgh, near Edinburgh.

1893. Burnes, Thomas, R.N., Homeleigh, Longton Avenue, Sydenham, London, S.E.

1878. Burnett, Robert Harvey, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1878. Burrell, Charles, Jun., Messrs. Charles Burrell and Sons, St. Nicholas Works, Thetford. [*Burrell, Thetford.*]

1887. Burstal, Edward Kynaston, Messrs. Stevenson and Burstal, 38 Parliament Street, Westminster, S.W.

1896. Burstall, Frederic William, Professor of Engineering, Mason University College, Birmingham.

1890. Burstall, Henry Robert John, Messrs. Burstall and Monkhouse, 14 Old Queen Street, Westminster, S.W. [*Advisedly, London.*]

1898. Burt, George (*Life Member*), Messrs. John Mowlem and Co., 19 Grosvenor Road, London, S.W.

1900. Bushell, Edward Hunter, 68 Orange Court, Liverpool.

1884. Butcher, Joseph John, P. O. Box 132, Thompsonville, Connecticut, United States.

1882. Butler, Edmund, Kirkstall Forge, near Leeds. [*Forge, Kirkstall.*]

1892. Butler, Henry William, Manager, Albert Hill Foundry, Darlington.

1884. Butler, Hugh Myddleton, Kirkstall Forge, near Leeds.

1891. Butler, James, Victoria Iron Works, Halifax; and Longfield, Halifax.

1891. Butter, Henry Joseph, Messrs. Tannett Walker and Co., Leeds; and Claremont, Burrage Road, Plumstead.

1894. Butterworth, Joseph, Messrs. Lancaster and Tonge, Pendleton, Manchester; and Thorn Cottage, Pendlebury, Manchester.

1899. Byrne, John Joseph, Barrow Bridge Iron Works, Athy, Ireland.

1887. Caiger, Emery John, Messrs. E. J. Caiger and Co., 92 Billiter Buildings, Billiter Street, London, E.C. [*Caiger, London.*]

1886. Cairnes, Frederick Evelyn, Killester House, Raheny, S. O., Co. Dublin.

1889. Callan, William, River Plate Fresh Meat Co., 2 Coleman Street, London, E.C.

1886. Cambridge, Henry, Stuart Chambers, Mount Stuart Square, Cardiff.

1898. Cameron, John, Taff Vale Railway, Cardiff.

1893. Campbell, Andrew Chisholm, Messrs. James Campbell and Sons, Vulcan Engine Works, William Moult Street, Liverpool.

1877. Campbell, Angus, Logie, Mussoorie, N. W. Provinces, India.

1880. Campbell, Daniel, Messrs. Campbell, Macmaster and Co., 11 and 12 Clement's Lane, Lombard Street, London, E.C. [*Duke, London.* Avenue 2011.]; and 18 Algiers Road, Lewisham, London, S.E.

1898. Campbell, Hugh, Campbell Gas Engine Co., Kingston, Halifax. [*Camgas, Halifax.* 92.]

1869. Campbell, James, Hunslet Engine Works, Leeds. [*Engineco, Leeds.*]

1893. Campbell, James Alexander Miller, Messrs. James Campbell and Sons, Vulcan Engine Works, William Moult Street, Liverpool.

1882. Campbell, John, Messrs. R. W. Deacon and Co., Kalimaas Works, Soerabaya, Java.

1899. Campbell, Robert Malcolm, Paris Singer Co., 157 and 165 Manor Street, Clapham, London, S.W. [*Forgive, London.* Battersea 228.]

1892. Campbell, William Walker, Messrs. Campbell and Calderwood, Soho Engine Works, Paisley. [*Soho, Paisley.* 162.]

1885. Capito, Charles Alfred Adolph, 5 Eardley Crescent, Earl's Court, London, S.W.

1892. Capper, David Sing, Professor of Mechanical Engineering, King's College, Strand, London, W.C.

1898. Capron, Athol John, Green Oak, Totley, Sheffield.

1860. Carbutt, Sir Edward Hamer, Bart., 19 Hyde Park Gardens, London, W.; and Nanhurst, Cranleigh, Guildford.

1878. Cardew, Cornelius Edward, Locomotive and Carriage Superintendent, Burma Railways Co., Insein, Burma.

1875. Cardozo, Francisco Corrêa de Mesquita (*Life Member*), Messrs. Cardozo and Irmâo, Pernambuco Engine Works, Pernambuco, Brazil: (or care of Messrs. Fry Miers aud Co., 8 Great Winchester Street, London, E.C.)

1892. Carnegie, David, Royal Laboratory, Royal Arsenal, Woolwich.

1899. Carnt, Edwin Charles, Messrs. J. Samuel White and Co., Cowes, Isle of Wight. [*White, East Cowes.* 3 A.]

1895. Carr, Robert Alfred, Engineer and Locomotive Superintendent, Burry Port and Gwendraeth Valley Railway, Burry Port, R.S.O., Carmarthenshire.

1892. Carrack, Charles, Messrs. Crossley Brothers, 116 New Street, Birmingham.

1884. Carrick, Henry, Messrs. Carrick and Wardale, Redheugh Engine Works, Gateshead; and Hall Garth, Coatham Mundeville, Darlington. [*Wardale, Gateshead.*]

1885. Carter, Herbert Fuller, Babcock and Wilcox Co., Apartado Postal 416, Mexico D.F., Mexico: (or care of H. Maynard Carter, 79 Wool Exchange, Coleman Street, London, E.C.)

1877. Carter, William, General Manager, The Hydraulic Engineering Company, Chester.

1888. Castle, Frank, Royal College of Science, Exhibition Road, South Kensington, London, S.W.

1891. Caswell, Samuel John, care of Messrs. A. C. Sim and Co., 18 Concession, Kobe, Japan.

1892. Causer, William George, Brighton Villa, Handsworth, R.O., Birmingham.

1883. Cawley, George, 29 Great George Street, Westminster, S.W.

1892. Chadwick, Osbert, C. M. G., Crown Agents' Department, Colonial Office, Downing Street, London, S.W.; and 11 Airlie Gardens, Kensington, London, W.

1894. Chaffey, George, 226 Spring Street, Los Angeles, California, United States.

1876. Challen, Stephen William, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham. [*Derwent, Birmingham.*]

1889. Challen, Walter Bernard, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham.

1892. Chalmers, George, St. John del Rey Mining Co., Finsbury House, Blomfield Street, London, E.C.

1886. Chalmers, John Reid, 18 Hemingford Road, Barnsbury, London, N.

1897. Chambers, Edward John, Managing Director, Messrs. Bullers, Tipton.

1896. Chambers, Robert Martin, Messrs. Chambers and Co., Cuba Street, Belfast.

1890. Chandler, Noel, Cannock Chase Foundry and Engine Works, Hednesford, near Stafford.

1888. Chapman, Arthur, Assam Railways and Trading Co., 1 Clive Ghat Street, Calcutta, India; The New Club, Calcutta, India: (or Hulne Park, Alnwick.)

1866. Chapman, Henry, 69 Victoria Street, Westminster, S.W. [*Tubalcain, London.*]; and 10 Rue Laffitte, Paris.

1878. Chapman, James Gregson, Messrs. Fawcett Preston and Co., Phœnix Foundry, Liverpool; and 25 Austinfriars, London, E.C. [*Fawcett, London.*]

1887. Chapman, Joseph Crawhall, 70 Chancery Lane, London, W.C.; and St. Mildred's, Lovelace Gardens, Surbiton.

1898. Chapman, Leonard, Sail Street, Lambeth, London, S.E.; and Runnymede, Hampton Wick, London, S.W.

1893. Charlesworth, Sheard, Messrs. S. Charlesworth and Co., Richmond Hill Iron Works, Oldham. [*Charlesworth, Engineers, Oldham.* 63.]

1885. Charnock, George Frederick, Engineering Department, Technical College, Bradford.

1877. Chater, John, Messrs. Henry Pooley and Son, 89 Fleet Street, London, E.C.

1890. Chater, John Richard, Messrs. Henry Pooley and Son, 28 Mosley Street, Newcastle-on-Tyne.

1885. Chatfeild Clarke, Leslie, 47 Queensborough Terrace, Hyde Park, London, W.

1891. Chatterton, Alfred, Professor of Engineering, College of Engineering, Madras, India.

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1887. Chatwin, James, Victoria Works, Great Tindal Street, Ladywood, Birmingham.

1867. Chatwood, Samuel, Lancashire Safe and Lock Works, Bolton; and High Lawn, Broad Oak Park, Worsley, near Manchester.

1898. Chatwood, Samuel Rawsthorne, Manager, Lancashire Safe and Lock Works, Bolton. [*Chatwoods, Bolton.* 333.]

1873. Cheesman, William Talbot, Hartlepool Rope Works, Hartlepool.

1897. Childe, Henry Slade, Messrs. Childe and Rowand, Wakefield. [*Childe, Wakefield.* 33.]

1895. Chittenden, Edmund Barrow, West Malling, Kent.

1899. Christie, Andrew, Mort's Dock and Engineering Co., Mort's Bay, Sydney, New South Wales.

1880. Churchward, George Dundas, Metropolitan Railway Carriage and Wagon Co., Saltley Works, Birmingham.

1894. Churchward, George Jackson, Great Western Railway Carriage Works, Swindon.

1896. Claremont, Ernest Alexander, Messrs. F. H. Royce and Co., Cooke Street, Hulme, Manchester. [*Switch, Manchester.* 772.]

1891. Clark, Augustus, Bowman's Heirs, Pernambuco, Brazil.

1867. Clark, George, Southwick Engine Works, near Sunderland.

1896. Clark, George, Jun., Southwick Engine Works, near Sunderland.

1899. Clark, Henry, Messrs. Head, Wrightson and Co., Stockton-on-Tees.

1889. Clark, Thomas Alexander, Superintendent of Workshops, George Heriot's Hospital School, Edinburgh.

1896. Clark, Thomas Forster, Locomotive Superintendent, Metropolitan Railway, Neasden, London, N.W.

1893. Clarke, Edward Fuhrmann, Curzon Chambers, Paradise Street, Birmingham; and 59 Stanmore Road, Edgbaston, Birmingham.

1894. Clarkson, Charles, Chester Road, Erdington, Birmingham.

1900. Clarkson, Edward Joseph, Clyde Engineering Co., Granville, New South Wales.

1898. Clarkson, James, Messrs. J. and P. Coats, 89 Wellington Street, Glasgow.

1891. Clarkson, Thomas, Clarkson and Capel Steam Car Syndicate, Deverell Street, London, S.E. [*Supersede, London.* Hop 141.]

1892. Clay, Charles Butler, National Telephone Co., St. Andrew's House, Holborn Circus, London, E.C.

1882. Clayton, William Wikeley, Messrs. Hudswell Clarke and Co., Railway Foundry, Jack Lane, Leeds. [*Loco, Leeds.* Central 504.]

1890. Cleathero, Edward Thomas, The Hollies, Barrington Road, Altrincham.

1890. Cleaver, Arthur, Engineer, Nottingham Laundry Co., Sherwood, near Nottingham; and Hornby House, Sherwood, near Nottingham.

1890. Cleland, William, Sheffield Testing Works, Blonk Street, Sheffield.

1873. Clench, Frederick, Lincoln Works, Chesterfield.

1897. Clifford, Charles, Chief Mechanical Engineer, Great Northern Railway of Ireland, Dundalk.

1885. Clifton, George Bellamy, Great Western Railway Electric Light Works, 150 Westbourne Terrace, Paddington, London, W.

1885. Close, John, York Engineering Works, Leeman Road, York.

1885. Clutterbuck, Herbert, Engineers' Department, London County Council, Spring Gardens, London, S.W.

1881. Cochrane, Brodie, Greencroft Park, Lanchester, Durham.

1887. Cochrane, George, Resident Engineer, London Hydraulic Power Works, 46 Holland Street, Blackfriars Road, London, S.E.

1885. Cochrane, John, Grahamston Foundry and Engine Works, Barrhead, near Glasgow. [*Cochrane, Barrhead.*]

1869. Cochrane, Joseph Bramah, Woodside Iron Works, near Dudley.

1868. Cochrane, William, Oakfield House, Gosforth, Newcastle-on-Tyne.

1864. Coddington, Sir William, Bart., M.P., Ordnance Cotton Mill, Blackburn; and Wycollar, Blackburn.

1889. Coey, Robert, Locomotive Engineer, Great Southern and Western Railway, Inchicore Works, near Dublin.

1898. Coker, Ernest George, McGill University, Montreal, Canada.

1889. Colam, William Newby, 57 Henderson Row, Edinburgh. [*Colam, Cable, Edinburgh.*]

1892. Cole, Henry Aylwin Bevan, 79½ Gracechurch Street, London, E.C. [*Carbuncle, London.*]

1878. Coles, Henry James, London Crane Works, Derby.

1894. Collis, Alfred Edward, Lincoln Science School, Monk's Road, Lincoln.

1884. Coltman, John Charles, Messrs. Huram Coltman and Son, Engineering Works, Meadow Lane, Loughborough.

1878. Colyer, Frederick, 14 Victoria Street, Westminster, S.W.

1888. Combe, Abram, Messrs. Combe Barbour and Combe, Falls Foundry, Belfast.

1896. Conaty, George, Engineer, Birmingham and Midland Tramways, Birmingham.

1888. Constantine, Ezekiel Grayson, 17 St. Ann's Square, Manchester. [*Constant, Manchester.*]

1886. Conyers, Sidney Ward, Railway Construction Branch, Public Works Department, Sydney, New South Wales.

1874. Conyers, William, New Zealand Chambers, 483 Collins Street, Melbourne, Victoria.

1896. Cook, Charles, Messrs. Barry, Henry and Co., 64 Mark Lane, London, E.C.

1888. Cook, John Joseph, Messrs. Robinson Cooks and Co., Atlas Foundry, St. Helens, Lancashire.

1892. Cooke, Rupert Thomas, 889 Ashton Old Road, Manchester.

1877. Cooper, Arthur, North Eastern Steel Co., Royal Exchange, Middlesbrough.

1883. Cooper, Charles Friend, 6 Wardrobe Place, Doctors' Commons, London, E.C.

1877. Cooper, George, Pencliffe, Alleyne Road, West Dulwich, London, S.E.

1898. Cooper, Henry, Messrs. Vickers, Sons and Maxim, River Don Works, Sheffield.

1891. Cooper, Myles, 36 Victoria Street, Manchester.

1874. Cooper, William, Neptune Engine Works, Hull. [*Neptune, Hull.*]

1881. Coote, Arthur, Messrs. R. and W. Hawthorn Leslie and Co., Hebburn, Newcastle-on-Tyne.

1885. Coppée, Evence, 223 Avenue Louise, Bruxelles, Belgium.

1899. Copperthwaite, Ralph Atkinson, 45 Victoria Road, Darlington.

1892. Corin, Philip Burne, Messrs. J. M. B. Corin and Son, Anchor Foundry, Penzance.

1895. Corner, John Frederick, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.

1895. Cornish, Edwin, Fleet Engineer, R.N., H.M.S. "Venerable," Chatham.

1848. Corry, Edward (*Life Member*), 9 New Broad Street, London, E.C.

1881. Cosser, Thomas, McLeod Road Iron Works, Karachi, India: (or care of Messrs. Ironside Gyles and Co., 1 Gresham Buildings, Guildhall, London, E.C.)

1900. Cotton, Charles Cathrow Carne, Messrs. Yarrow and Co., Isle of Dogs, Poplar, London, E.

1883. Cotton, Henry Streatfeild, Oaklands, Isfield, near Uckfield.

1896. Cottrell, Stephen Butler, Pacific Buildings, 31 James Street, Liverpool. [*Motor, Liverpool.* Central 5460.]

1894. Cottrill, John Ormerod, Bee Hive Works, Bolton.

1887. Coulman, John, Assistant Locomotive Superintendent, Hull and Barnsley Railway, Spring Head Works, Hull.

1895. Couper, Sinclair, Messrs. Lindsay Burnet and Co., Moore Park Boiler Works, Govan, Glasgow. [*Burnet, Glasgow.* South Side 1513.]

1878. Courtney, Frank Stuart, Messrs. Easton Anderson and Goolden, Broad Sanctuary Chambers, Broad Sanctuary, Westminster, S.W.; and 39 Alleyn Park, Dulwich, London, S.E.

1899. Coveney, William Charles, Superintendent Engineer, Municipal Pumping Station, Singapore, Straits Settlements.

1875. Coward, Edward, Messrs. Melland and Coward, Cotton Mills and Bleach Works, Heaton Mersey, near Manchester.

1896. Cowdell, Henry Charles, Cradley Boiler Works, Cradley Heath, S.O., Staffordshire. [*Boiler, Cradley Heath.*]

1893. Cowell, John Ray, P.O. Box 2141, Johannesburg, Transvaal, South Africa.

1875. Cowen, Edward Samuel, Messrs. G. R. Cowen and Co., Beck Works, Brook Street, Nottingham; and 9 The Ropewalk, Nottingham. [*Cowen, Nottingham.* 87.]

1898. Cowen, George Roberts, 9 The Ropewalk, Nottingham.

1898. Cowens, William Edward, Works Manager, Messrs. John Abbot and Co., Park Works, Gateshead.

1880. Cowper, Charles Edward, 144 Addison Gardens, London, W.

1892. Cowper-Coles, Sherard Osborn, Grosvenor Mansions, Victoria Street, Westminster, S.W. [*Zincking, London.*]

1888. Cox, Herbert Henry, 17 Wodehouse Terrace, Falmouth.

1897. Cox, Job, Birmingham Corporation Baths and Parks Departments, Kent Street, Birmingham. [994.]

1896. Craig, Alexander, Messrs. A. and G. Craig, Queen's Quay and Boating Club Road, Londonderry.

1899. Craven, John Alfred, Darnall Railway Carriage, Wagon, and Wheel Works, Sheffield.

1866. Craven, William, Messrs. Craven Brothers, Vauxhall Iron Works, Osborne Street, Manchester. [*Vauxhall, Manchester.* 659.]

1894. Craven, William H. S., Messrs. Craven Brothers, Vauxhall Iron Works, Osborne Street, Manchester. [*Vauxhall, Manchester.* 659.]

1897. Crawford, Walter William, 91 Pitt Street, Sydney, New South Wales. [*Carbonic, Sydney.* 2362.]

1898. Crewe, Henry Thomas, 78 Queen Victoria Street, London, E.C.

1889. Cribb, Frederick James, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.

1893. Crippin, Thomas Henry, Bolton Engineering Co., Turton Street, Bolton; and 89 Bury New Road, Bolton.

1897. Critchley, James Sidney, Works Manager, Daimler Motor Co., Motor Mills, Coventry.

1883. Croft, Henry, M.P., Chemanns, Vancouver Island.

1899. Crofts, John Charles Thruston, Messrs. Fergusson and Crofts, 603 Hastings Street, Vancouver, British Columbia. [*Fergusson, Vancouver.* 595.]

1878. Crohn, Frederick William, 14 Burney Street, Greenwich, London, S.E.

1877. Crompton, Rookes Evelyn Bell, Arc Works, Chelmsford; and Mansion House Buildings, Queen Victoria Street, London, E.C. [*Crompton, Chelmsford.*]

1898. Cronin, Richard, Locomotive Superintendent, Dublin, Wicklow and Wexford Railway, Upper Grand Canal Street, Dublin.

1884. Crook, Charles Alexander, Telegraph Construction and Maintenance Works, Enderby's Wharf, East Greenwich, London, S.E.

1881. Crosland, James Foyell Lovelock, Chief Engineer, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.

1891. Crosland, Joseph, Messrs. Seebohm and Dieckstahl, Dannemora Steel Works, Sheffield; and Stanley Avenue, Birkdale, Southport.

1875. Crossley, William John, Messrs. Crossley Brothers, Great Marlborough Street, Manchester. [*Crossleys, Openshaw.*]

1882. Cruickshank, William Douglass, Chief Government Engineer Surveyor, Marine Board, Sydney, New South Wales.

1898. Cruttwell, George Edward Wilson, 8 Queen Anne's Gate, Westminster, S.W. [*Cruttwell, London.* Westminster 571.]

1898. Cullen, Peter John, Messrs. Henry Simon, 333 Kent Street, Sydney, New South Wales.

1889. Cullen, William Hart, Resident Engineer, The Aluminium Co., Oldbury, near Birmingham.

1887. Cutler, George Benjamin, Messrs. Samuel Cutler and Sons, Providence Iron Works, Millwall, London, E.; and 10 St. John's Park, Blackheath, London, S.E. [*Cutler, Millwall.* Eastern 59.]

1876. Cutler, Samuel, Messrs. Samuel Cutler and Sons, Providence Iron Works, Millwall, London, E. [*Cutler, Millwall.* Eastern 59.]

1891. Cutler, Samuel, Jun., Messrs. Samuel Cutler and Sons, Providence Iron Works, Millwall, London, E. [*Cutler, Millwall.* Eastern 59.]

1888. Dadabhoy, Cursetjee, Messrs. Shapurji Sorabji and Co., Bombay Foundry and Engine Works, Khetwady, Bombay, India, and Cumbala Hill, Bombay, India.

1891. Daglish, Harry Bolton, Messrs. Robert Daglish and Co., St. Helens Engine and Boiler Works, St. Helens, Lancashire.

1895. Daintree, Thomas Ekins, Alma Villa, Old Park Road, Hitchin.

1883. D'Albert, Charles, Société des Anciens Établissements Hotchkiss et Cie., 6 Route de Gonesse, St. Denis, Seine, France.

1890. Dalby, William Ernest, Professor of Mechanical Engineering, City and Guilds of London Institute: Finsbury Technical College, Leonard Street, City Road, London, E.C.

1889. Dalgarno, James Robert, 454 Great Western Road, Aberdeen.

1893. Dall, John, Messrs. F. Leyland and Co., Atlantic Engine Works, Bootle, Liverpool.

1893. Dalrymple, Alexander, Superintendent Engineer, Hall Line of Steamers, 19 Tower Buildings N., Water Street, Liverpool.

1881. D'Alton, Patrick Walter, London Electric Supply Corporation, Stowage Wharf, Deptford, London, S.E.

1899. Dan, Takuma, Mitsui Mining Co., 9 Yamashiro-cho, Kio-bashi-ku, Tokyo, Japan.

1899. Dania, George, 110 Cannon Street, London, E.C.

1866. Daniel, Edward Freer, Messrs. Worthington and Co., The Brewery, Burton-on-Trent; and 89 Derby Street, Burton-on-Trent.

1866. Daniel, William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds; and Fern Bank, Horsforth, Leeds.

1891. Daniels, Thomas, Messrs. Nasmyth Wilson and Co., Patricroft, Manchester.

1888. Darbishire, James Edward, 110 Cannon Street, London, E.C. [*Ezra, London.* Avenue 306.]

1878. Darwin, Horace (*Life Member*), The Orchard, Huntingdon Road, Cambridge.

1873. Davey, Henry, Messrs. Hathorn Davey and Co., Sun Foundry, Dewsbury Road, Leeds [*Sun Foundry, Leeds*]; and 3 Prince's Street, Westminster, S.W. [*Subterranean, London.*]

1890. Davidson, Albert, 139 Norfolk Street, Sheffield.

1888. Davidson, Samuel Cleland, Sirocco Works, Bridge End, Belfast.

1880. Davies, Charles Merson, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow; and Leslie House, Pollokshields, Glasgow.

1897. Davies, Edmund Joseph, Messrs. Ransomes, Sims and Jefferies, Orwell Works, Ipswich.

1885. Davies, Edward John Mines, 24 Harrington Square, London, N.W.

1891. Davies, John Hubert, P.O. Box 1386, Johannesburg, Transvaal, South Africa.

1894. Davis, George, Engineer's Office, Lancashire and Yorkshire Railway, Hunt's Bank, Manchester.

1877. Davison, John Walter, Bombay Baroda and Central India Railway, Ahmedabad, India: (or care of Mrs. Channon, 97 Shirland Road, Maida Vale, London, W.)

1884. Davison, Robert, Locomotive Department, Caledonian Railway, St. Rollox, Glasgow.

1873. Davy, David, Broom Croft, Parkhead, Sheffield.

1892. Davy, William James, 27 Drayton Park, Highbury, London, N.

1874. Daw, Samuel, 50 Chelsea Road, Southsea, Portsmouth.

1879. Dawson, Bernard, 110 Cannon Street, London, E.C. [*Crocus, London*]; and The Laurels, Malvern Link, Malvern. [*Heather, Malvern Link.*]

1875. Dawson, Edward, 23 Park Place, Cardiff. [*Mechanical, Cardiff.*]

1896. Dawson, Philip, 39 Victoria Street, Westminster, S.W.

1896. Day, Charles, Messrs. S. Z. de Ferranti, Hollinwood, Manchester.

1890. Day, George Cameron, Messrs. Day Summers and Co., Northam Iron Works, Southampton; and 29 Carlton Crescent, Southampton.

1886. Dayson, William Ogden, Blaenavon Works, Blaenavon, R.S.O., Monmouthshire.

1874. Deacon, George Frederick, Great George Street Chambers, 16 Great George Street, Westminster, S.W.

1880. Deacon, Richard William, Glenthorne, Astwood, Worcester.

1894. Deakin, Benjamin Walter, British Insulated Wire Co., 65 Queen Street, Melbourne, Victoria.

1868. Dean, William, Locomotive Superintendent, Great Western Railway, Swindon.

1899. Deas, James, Chief Engineer, Water, Sanitary and Electric Lighting Departments, Municipal Offices, Warrington.

1890. Deeley, Richard Mountford, Locomotive Department, Midland Railway, Derby; and 38 Charnwood Street, Derby.

1889. Defries, Wolf, Messrs. Defries and Sons, 147 Houndsditch, London, E. [*Defries, London.*]

1882. Denison, Samuel, Messrs. Samuel Denison and Son, Hunslet Foundry, Leeds. [*Weigh, Leeds.* Central 1238.]

1892. Dennis, George D., 26 Newton Road, Bayswater, London, W.

1900. Denny, John, Messrs. Denny Brothers, Fremantle, Western Australia.

1888. Dent, Charles Hastings, London and North Western Railway, Lime Street Station, Liverpool.

1898. De Ritter, Walter Henry, 33 Three Colt Street, Limehouse, London, E. [*Deritter, London.*]

1895. Dewhurst, John Henry, Messrs. John Dewhurst and Son, Attercliffe Road, Sheffield. [1614.]

1899. Dewrance, John, 165 Great Dover Street, London, S.E.; and Cranmore Place, Chislehurst.

1883. Dick, Frank Wesley, Palmers Shipbuilding and Iron Works, Jarrow.

1891. Dick, John Norman, Government Marine Surveyor, Penang, Straits Settlements.

1890. Dickinson, Alfred, Telephone Buildings, Birmingham. [*Traction, Birmingham.* 1823.]

1894. Dickinson, Harold, Central Electric Lighting Station, Yorkshire House to House Electricity Co., Whitehall Road, Leeds. [*Electricity, Leeds.* Central 1013.]

1891. Dickinson, James Clark, Palmer's Hill Engine Works, Sunderland.

1880. Dickinson, John, Palmer's Hill Engine Works, Sunderland. [*Bede, Sunderland.*]

1892. Dickinson, Richard Henry, Locomotive Superintendent, Birmingham Central Tramways, Kyotts Lake Depôt, Birmingham.

1875. Dickinson, William, Warham Road, Croydon.

1899. Ditchburn, Robert, Superintending Engineer, Bombay Steam Navigation Co., Bombay, India.

1886. Dixon, Robert, Oakfield, Lymm, Warrington.

1883. Dixon, Samuel, Messrs. Kendall and Gent, Victoria Works, Belle Vue, Manchester. [*Tools, Manchester.* 5147.]

1898. Dixon, Walter, 59 Bath Street, Glasgow. [*Fresco, Glasgow.* 3656.]

1897. Dixon, Walter Frank, Chief Engineer, Locomotive Department, Sormovo Works, Nijni Novgorod, Russia.

1887. Dixon, William Basil, Messrs. John Penn and Sons, Greenwich, London, S.E.

1896. Dobson, Adam, 58 Clifton Park Avenue, Belfast.

1899. Dobson, Sydney Thornton, Chief Engineer, St. James's and Pall Mall Electric Light Co., 19 Carnaby Street, Golden Square, London, W. [*Fulleresco, London.* Gerrard 5082.]

1880. Dodd, John, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1868. Dodman, Alfred, Highgate Foundry, Lynn. [*Dodman, Lynn.*]

1889. Dolby, Ernest Richard, Messrs. Dolby and Williamson, 8 Prince's Street, Westminster, S.W.

1898. Donaldson, Hay Frederick, Deputy Director General of Ordnance Factories, Royal Arsenal, Woolwich; and Wood Lodge, Shooter's Hill, Kent.

1873. Donkin, Bryan (*Life Member*), Messrs. Bryan Donkin and Co., 55 Southwark Park Road, Bermondsey, London, S.E. [*Donkin Company, London.* Hop 662.]; and The Mount, Wray Park, Reigate.

1895. Donkin, Harry Julyan, Works Manager, Messrs. Bryan Donkin and Co., 55 Southwark Park Road, Bermondsey, London, S.E.

1891. Donovan, Edward Wynne, Messrs. J. S. Leach and Co., Broughton Bridge Iron Works, Salford, Manchester. [*Dazzle, Manchester.*]

1896. Dorman, William Sansom, Works Manager, Gloucester Wagon Works, Gloucester.

1865. Douglas, Charles Prattman (*Life Member*), Thornbeck Hill, Carmel Road, Darlington.

1879. Douglass, William, Chief Engineer to the Commissioners of Irish Lights, Westmoreland Street, Dublin.

1891. Douglass, William James, Messrs. Douglass Brothers, Globe Iron Works, Blaydon-on-Tyne, R.S.O., County Durham.

1887. Douglass, William Tregarthen, 15 Victoria Street, Westminster, S.W.

1857. Dove, George, Messrs. Cowans Sheldon and Co., St. Nicholas Engine and Iron Works, Carlisle; and Viewfield, Stanwix, near Carlisle.

1873. Dove, George, Redbourn Hill Iron and Coal Co., Frodingham, near Doncaster [*Redbourn, Frodingham.*]; and Hodroyd Hall, near Barnsley.

1866. Downey, Alfred C., Messrs. Downey and Co., Coatham Iron Works, Middlesbrough; and Belle Vue, Marton Road, Middlesbrough.

1881. Dowson, Joseph Emerson, 39 Old Queen Street, Westminster, S.W. [*Gaseous, London.*]

1880. Doxford, Robert Pile, Messrs. William Doxford and Sons, Pallion Shipbuilding and Engine Works, Sunderland.

1874. Dredge, James, C.M.G., 35 Bedford Street, Strand, London, W.C. [Gerrard 3663.]

1899. Drew, Alexander. 22 Rutland Square, Edinburgh.

1890. Drewet, Tom, Government Senior Inspector of Steam Boilers, Town Custom House, Bombay, India.

1898. Dronsfield, Joseph Standring, Messrs. Dronsfield Brothers, Atlas Works, Oldham.

1896. Dronsfield, William, Messrs. Dronsfield Brothers, Atlas Works, Oldham.

1886. Drummond, Dugald, Locomotive Engineer, London and South Western Railway, Nine Elms, London, S.W.

1898. Drummond, George William, Glasgow Railway Engineering Co., 53 Victoria Street, Westminster, S.W. [*Azabra, London.*]

1898. Drummond, Peter, Locomotive Superintendent, Highland Railway, Inverness.

1899. Drummond, Walter, Glasgow Railway Engineering Co., Govan, Glasgow.

1900. Dryden, Albert, H.M. Mint, Calcutta, India: (or care of Messrs. Grindlay and Co., 55 Parliament Street, Westminster, S.W.)

1896. Dryden, Thomas, Grimshaw Street Foundry, Preston. [36.]

1877. Dübs, Charles Ralph, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.

1885. Duckering, Charles, Water Side Works, Rosemary Lane, Lincoln.

1900. Dudin, Henry William, Messrs. Yarrow and Co., Isle of Dogs, Poplar, London, E.

1868. Dugard, William Henry, Messrs. Dugard Brothers, Vulcan Rolling Mills, Bridge Street West, Summer Lane, Birmingham. [*Vulcan, Birmingham.*]

1879. Duncan, David John Russell, 28 Victoria Street, Westminster, S.W.

1886. Duncan, Norman, Mechanical Engineer to the Municipality, Rangoon, British Burmah, India.

1894. Dunell, George Robert, 36 Bedford Street, Strand, London, W.C.; and 7 Spencer Road, Grove Park, Chiswick, London, W.

1898. Dunkerley, Stanley, Professor of Applied Mechanics, Royal Naval College, Greenwich, London, S.E.

1892. Dunlop, James, Victoria Jubilee Technical Institute, Byculla, Bombay, India.

1870. Dunlop, James Wilkie, 39 Delancey Street, Regent's Park, London, N.W.

1899. Dunn, Andrew Macfarlane, Works Manager, Messrs. J. and P. Coats, Ferguslie Thread Works, Paisley.

1890. Dunn, Hugh Shaw, Engineer, Caprington Collieries, Kilmarnock.

1895. Dunn, Matthew, Engineer, Gas and Water Department, Urban District Council, Goole.

1899. Durston, Sir Albert John, K.C.B., R.N., Engineer-in-Chief, Admiralty, Whitehall, London, S.W.

1886. Duvall, Charles Anthony, Haseley Iron Works, Tetsworth.

1865. Dyson, Robert, Messrs. Owen and Dyson, Rother Iron Works, Rotherham.

1880. Eager, John Edward, Messrs. William Crichton and Co., Engineering and Shipbuilding Works, Abo, Finland.

1858. Easton, Edward, 11 Delahay Street, Westminster, S.W.

1884. Eastwood, Charles, Manager, Linacre Gas Works, Liverpool.

1892. Eastwood, Thomas Carline, Messrs. Eastwood Swingler and Co., Victoria and Railway Iron Works, Derby. [*Swingler, Derby.*]

1888. Eaton-Shore, George, Borough Engineer, Temple Chambers, Crewe.

1896. Eborall, Cornelius Willes, District Locomotive Superintendent, East Indian Railway, Jamalpur, India: (or care of Messrs. William Watson and Co., 7 Waterloo Place, Pall Mall, London, S.W.)

1897. Echevarri, Juan Thomas Wood, British Aluminium Co., 9 Victoria Street, Westminster, S.W.

1878. Eckart, William Roberts, Room 4, Nevada Block, San Francisco; and 3014 Clay Street, San Francisco, California, United States.

1868. Eddison, Robert William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1886. Ede, Francis Joseph, Messrs. Ede Brothers, Silchar, Cachar, India.

1892. Edgcome, James Edmund, Borough Electrical Engineer, Kingston-on-Thames.

1883. Edmiston, James Brown, Marine Superintending Engineer, Messrs. Hamilton Fraser and Co., K Exchange Buildings, Liverpool; and Ivy Cottage, Highfield Road, Walton, Liverpool.

1877. Edwards, Frederick, 62 Bishopsgate Street Within, London, E.C.

1891. Edwards, Herbert Francis, Messrs. Forster, Brown and Rees, Guildhall Chambers, Cardiff.

1885. Edwards, Walter Cleeve, Public Works Department, Cape Town, Cape Colony.

1896. Ekin, Tom Charles, 21 Old Queen Street, Westminster, S.W.

1899. Elford, Ernest John, Water Engineer, Water Engineer's Department, New Road, Portland.

1888. Ellery, Henry George, 7 Fernbank Road, Redland, Bristol.

1875. Ellington, Edward Bayzand, Hydraulic Engineering Works, Chester; and Hydraulic Engineering Co., Palace Chambers, 9 Bridge Street, Westminster, S.W.

1892. Elliott, Archibald Campbell, D.Sc., Professor of Engineering, University College of South Wales and Monmouthshire, Cardiff.

1895. Elliott, George, 2 Clarinda, Cavehill Road, Belfast.

1883. Elliott, Henry John, Elliott's Metal Company, 22 Leadenhall Buildings, Leadenhall Street, London, E.C.

1895. Ellis, Arthur Devonshire, Managing Director, Messrs. Thwaites Brothers, Vulcan Iron Works, Bradford.

1896. Ellis, William Frederick Wood, 2 Dulal Street, Fort, Bombay, India; and 23 Waldemar Avenue, Fulham, London, S.W.

1900. Elmer, Joseph John, Works Manager, Westinghouse Brake Co., 82 York Road, King's Cross, London, N.

1897. Elsworth, John Francis, Les Huileries, Alexandria, Egypt.

1885. Elsworthy, Edward Houtson, Messrs. Richardson and Cruddas, Byculla Iron Works, Bombay, India; and The Ridge, Malabar Hill, Bombay, India.

1878. Elwin, Charles, London County Council, Spring Gardens, London, S.W.

1890. English, Lt.-Colonel Thomas, Hawley, near Dartford.

1894. English, Thomas Matthew, Superintendent, Die and Coining Department, H. M. Mint, Bombay, India.

1894. Ennor, Charles John, 55 Rua da Reboleira, Oporto, Portugal.

1890. Esson, John, Chatteris Engineering Works, Chatteris, S.O., Cambridgeshire.

1884. Etherington, John, 39A King William Street, London Bridge, London, E.C.

1887. Evans, Arthur George, Palace Chambers, 9 Bridge Street, Westminster, S.W.; and Kington Langley, Chippenham.

1884. Evans, David, Messrs. Bolckow Vaughan and Co., Cleveland Iron and Steel Works, South Bank, R.S.O., Yorkshire.

1887. Everitt, Nevill Henry, Messrs. Thomas Piggott and Co., Atlas Works, Birmingham; and Hillside, Knowle, Warwickshire.

1897. Evers, Joseph Henry, General Manager, Messrs. Manning, Wardle and Co., Boyne Engine Works, Hunslet, Leeds. [*Manning, Leeds.*]

1894. Ewen, John Taylor, Millbank House, Forfar.

1881. Ewen, Thomas Buttwell, Messrs. Ewen and Mitton, Smithfield Works, Sherlock Street, Birmingham.

1891. Ewing, James Alfred, F.R.S., Professor of Mechanism and Applied Mechanics, Engineering Department, The University, Cambridge; and Langdale Lodge, Cambridge.

1890. Exton, George Gaskell, Messrs. Chubb and Son, 128 Queen Victoria Street, London, E.C.

1868. Fairbairn, Sir Andrew, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds; and Askham Richard, York.

1880. Farcot, Paul, Messrs. Farcot and Sons, Engine Works, 17 Avenue de la Gare, St. Ouen, France.

1881. Farrar, Sidney Howard, Messrs. Howard Farrar and Co., Port Elizabeth, South Africa; and care of Messrs. F. A. Robinson and Co., 54 Old Broad Street, London, E.C.

1900. Favell, Thomas Milnes, Wolstanton, Stoke-on-Trent.

1882. Feeny, Victor Isidore, 60 Queen Victoria Street, London, E.C. [*Victor Feeny, London.*]

1899. Feetham, Mark, Resident Engineer, Chapel Place Electric Lighting Station, Brompton Road, London, S.W.

1876. Fell, John Corry, 1 Queen Victoria Street, London, E.C.; and Excelsior Works, Old Street, London, E.C.

1869. Fenwick, Clennell, 57 Gracechurch Street, London, E.C.

1892. Fenwick, James, 19 Bridge Street, Sydney, New South Wales. [1038.]

1881. Ferguson, William, Harbour Board, Wellington, New Zealand: (or care of Montgomery Ferguson, 81 James Street, Dublin.)

1896. Ferguson, William Deeble, Albert Villa, Ravenhill Road, Belfast.

1866. Fiddes, Walter, 2 Queen's Avenue, Tyndall's Park, Bristol.

1867. Field, Edward, 4 Trafalgar Square, London, W.C.
1888. Field, Howard, 12 London Street, Fenchurch Street, London, E.C.
1884. Fielden, Joseph Petrie, Park Terrace, Rochdale.
1874. Fielding, John, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester. [*Atlas, Gloucester.*]
1891. Finlayson, Finlay, Clydeside Tube Works, Whifflet, Coatbridge.
1899. Firth, Ambrose, Messrs. Walker, Eaton and Co., Wicker Iron Works, Sheffield. [*Founder, Sheffield.* 373.]
1888. Fischer, Gustave Joseph, Railway Construction Branch, Public Works Department, Sydney, New South Wales; and Oakhurst, West Street, North Sydney, New South Wales.
1897. Fish, Sylvester Robert, Messrs. F. Street and Co., Palacio da Flôr da Murta, 156 Rua do Poço dos Negros 158, Lisbon, Portugal.
1889. Fisher, Henry Bedwell, Marine Shops, London Brighton and South Coast Railway, Newhaven, Sussex.
1884. Fisher, Henry Oakden, Ty Mynydd, Radyr, near Cardiff.
1897. Fisher, Pearson, Messrs. Edward Chester and Co., Renfrew, near Paisley.
1888. FitzGerald, Maurice Frederick, Professor of Engineering, Queen's College, Belfast.
1877. Flannery, Sir James Fortescue, M.P., 9 Fenchurch Street, London, E.C. [Avenue 338.]
1898. Fletcher, William, Messrs. Clayton and Shuttleworth, Stamp End Works, Lincoln.
1892. Focken, Charles Frederick, care of Institute of Engineers and Shipbuilders, Hong Kong, China.
1899. Footner, Harry, London and North Western Railway, Crewe.
1882. Forbes, David Moncur, Engineer, H. M. Mint, Bombay.
1892. Forbes, Percy Alexander, Messrs. Lambert Brothers, Tube Mills, Iron and Brass Works, Walsall.
1882. Forbes, William George Loudon Stuart, Mechanical Superintendent, H. M. Mint, Calcutta.
1899. Ford, Thomas Wharton, Palace Chambers, 9 Bridge Street, Westminster, S.W.
1899. Ford-Moore, Arthur Pilcher, Messrs. Stuart and Moore, Victoria Electrical Works, Ealing, London, W. [*Burning, London.*]
1892. Forrest, Hilary Sheldon, General Manager, Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton.
1888. Forster, Alfred Llewellyn, Assistant Engineer, Newcastle and Gateshead Water Works, Newcastle-on-Tyne.
1882. Forsyth, Robert Alexander, Courtway, Gold Tops, Newport, Monmouthshire.
1889. Foster, Ernest Howard, Worthington Pumping Engine Co., 153 Quee Victoria Street, London, E.C.

1889. Foster, Herbert Anderton (*Life Member*), Messrs. John Foster and Son, Black Dike Spinning Mills, Queensbury, near Bradford.

1888. Foster, James, Lily Bank, St. Andrew's Drive, Pollokshields, Glasgow.

1884. Foster, John Slater, Messrs. Jones and Foster, 39 Bloomsbury Street, Birmingham.

1882. Fothergill, John Reed, Consulting Engineer, Dock Office, West Hartlepool; and 1 Bathgate Terrace, West Hartlepool.

1877. Foulis, William, Manager, Glasgow Corporation Gas Department, City Chambers, 45 John Street, Glasgow.

1885. Fourny, Hector Foster, French Chambers, Queen's Dock-Side, Hull. [*Veritas, Hull.*]

1866. Fowler, George, Basford Hall, near Nottingham.

1896. Fowler, Henry, Lancashire and Yorkshire Railway, Horwich, near Bolton.

1894. Fowler, Robert Henry, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds. [*Fowler, Leeds.*]

1885. Fowler, William Henry, Hodson's Court, Corporation Street, Manchester; and Brook House, Flixton, near Manchester.

1900. Fox, Charles Heyland, Broad Street House, Old Broad Street, London, E.C.

1866. Fox, Sir Douglas, 28 Victoria Street, Westminster, S.W.

1875. Fox, Samson, Blairquhan Castle, Maybole; and Grove House, Harrogate.

1884. Frampton, Edwin, General Engine and Boiler Co., Hatcham Iron Works, Pomeroy Street, New Cross Road, London, S.E. [*Oxygen, London.*]

1885. Franki, James Peter, Mort's Dock and Engineering Co., Mort's Bay, Sydney, New South Wales: (or care of Messrs. Goldsbrough Mort and Co., 149 Leadenhall Street, London, E.C.)

1877. Fraser, John Hazell, Messrs. John Fraser and Son, Millwall Boiler Works, London, E.; and 110 Cannon Street, London, E.C.

1899. Fraser, Patrick, Messrs. Douglas Fraser and Sons, Westburn Foundry, Arbroath.

1866. Fry, Albert, Bristol Wagon Works, Lawrence Hill, Bristol.

1891. Fuller, Charles Frederick, 97 Queen Victoria Street, London, E.C.

1890. Gadd, William, Assistant Locomotive Engineer, Waterford and Limerick Railway, Limerick.

1866. Galloway, Charles John, Managing Director, Messrs. Galloways, Knott Mill Iron Works, Manchester. [*Galloway, Manchester.*]

1898. Gandy, Frederick, Staveley Coal and Iron Co., Chesterfield.

1884. Ganga Ram, Rai Bahadur, Executive Engineer, Public Works Department, Amritsar, Punjaub, India: (or care of Messrs. Thomas Wilson and Co., 10 and 12 Eastcheap, London, E.C.)

1899. Gardner, William, Vauxhall Iron Works Co., 45 Leadenhall Street, London, E.C. [*Wellhole, London.* Avenue 800.]

1891. Garrard, Charles Riley, Garrard Manufacturing Co., Magneto Works, Ryland Street, Birmingham. [*Gearing, Birmingham.* 904.]

1899. Garrard, George Mingay, Broseley, Shropshire.

1882. Garrett, Frank, Messrs. Richard Garrett and Sons, Leiston Works, Leiston, R.S.O., Suffolk. [*Garrett, Leiston.*]

1899. Garvie, James, Managing Director, Southgate Engineering Co., New Southgate, London, N. [*Centrifugal, New Southgate.*]

1894. Gatehouse, Tom Ernest, 4 Ludgate Hill, London, E.C. [*Ageekay, London.* Holborn 933.]

1888. Gaze, Edward Henry James, 4 Victoria Drive, Mount Florida, Glasgow.

1895. Geach, Frederick Samuel, United Alkali Co., Pilkington Works, Widnes.

1888. Geddes, Christopher, 2A Drury Buildings, Water Street, Liverpool. [*Graccius, Liverpool.*]

1880. Geoghegan, Samuel, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin [*Guinness, Dublin.*]

1896. German, Walter Hussey, Colonial Sugar Refining Co., Sydney, New South Wales.

1887. Gibb, Andrew, Managing Engineer, Messrs. Rait and Gardiner, Millwall Docks, London, E.; and Garthland, Westcombe Park Road, Blackheath, London, S.E.

1871. Gibbins, Richard Cadbury, Berkley Street, Birmingham. [*Gibbins, Birmingham.*]

1899. Gibson-Sugars, John Sugars, Chief Engineer, R.N., H M.S. "Pioneer," Chatham.

1883. Gilchrist, Percy Carlyle, F.R.S. (*Life Member*), Fern House, Witham, Essex.

1898. Giles, Benjamin, Divisional Superintendent, Great Western Railway, Newton Abbot.

1880. Gill, Charles, Messrs. Young and Gill, Engineering Works, Java; and Java Lodge, Beckenham.

1889. Gill, Frederick Henry, Messrs. Alexander Penney and Co., 107 Fenchurch Street, London, E.C.

1884. Gimson, Arthur James, Messrs. Gimson and Co., Engine Works, Vulcan Street, Leicester. [*Gimson, Leicester.* 6.]

1881. Girdwood, William Wallace, 24 Plashet Road, Upton Manor, London, E.

1896. Glasgow, Arthur Graham (*Life Member*), Messrs. Humphreys and Glasgow, 9 Victoria Street, Westminster, S.W.

1898. Glen, David Corse, Messrs. Matheson and Co., 3 Lombard Street, London, E.C.

1880. Godfrey, William Bernard, 23 St. Swithin's Lane, London, E.C.

1888. Goff, John, Messrs. Salt and Co., The Brewery, Burton-on-Trent.

1882. Goldsmith, Alfred Joseph, Lillington, Moray Street, New Farm, Brisbane, Queensland.

1877. Goodbody, Robert, Messrs. Goodbody, Clashawaun Jute Factory, Clara, near Moate, Ireland.

1875. Goodfellow, George Ben, Messrs. Goodfellow and Matthews, Hyde Iron Works, Hyde, near Manchester. [*Goodfellow, Hyde.*]

1890. Goodman, John, Professor of Engineering, Yorkshire College, Leeds.

1899. Goodwin, Albert Beecham, Engineers' Department, The Imperial Institute, Imperial Institute Road, London, S.W.

1889. Goold, William Tom, Shillingford Engineering Co., Trusty Engine Works, Cheltenham.

1865. Göransson, Göran Fredrick, Sandvik Iron Works, near Gefle, Sweden: (or care of James Bird, 143 Cannon Street, London, E.C.)

1887. Gordon, Alexander, Niles Tool Works, and Messrs. Gordon and Maxwell, Hamilton, Ohio, United States.

1879. Gorman, William Augustus, Messrs. Siebe and Gorman, 187 Westminster Bridge Road, London, S.E. [*Siebe, London.*]

1877. Goulty, Wallis Rivers, Kuruman, Leicester Road, Altrincham.

1878. Grafton, Alexander, Vulcan Works, Bedford. [*Grafton, Bedford.*]

1894. Graham, Maurice, Messrs. Graham, Morton and Co., Black Bull Street, Leeds.

1896. Graham, Robert, Ponce, Porto Rico.

1886. Grant, Percy, Assistant Locomotive, Carriage, and Wagon Superintendent, Sola Works, Ferro Carril del Sud, Buenos Aires, Argentine Republic: (or care of John M. Grant, 136 Sutherland Avenue, Maida Vale, London, W.)

1895. Grant, Thomas Maxwell, Managing Director, Messrs. Napier Brothers, 100 Hyde Park Street, Glasgow. [*Windlass, Glasgow.* 714.]

1891. Gray, George Macfarlane (*Life Member*), Board of Trade Surveyors' Office, Custom House Arcade, Liverpool.

1865. Gray, John Macfarlane, 4 Ladbroke Crescent, Notting Hill, London, W.

1879. Gray, Thomas Lowe (*Life Member*), Lloyd's Register, 2 White Lion Court, Cornhill, London, E.C.; and 24 St. Michael's Road, Stockwell, London, S.W.

1900. Greaven, Andrew Augustine, Works Manager, Sola Works, Ferro Carril del Sud, Buenos Aires, Argentine Republic.

1898. Greaven, Louis, Locomotive, Carriage and Wagon Superintendent, Inter-Oceanic Railway, Puebla, Mexico: (or care of F. Nolan, 17 Beach, Queenstown, Co. Cork.)

1861. Green, Sir Edward, Bart., Messrs. E. Green and Son, Phœnix Works, Wakefield.

1898. Green, Thomas Willoughby, Messrs. Thomas Green and Son, Smithfield Iron Works, Leeds. [*Smithfield, Leeds.* Central 158.]

1893. Green, William Penrose, Messrs. Thomas Green and Son, Smithfield Iron Works, Leeds. [*Smithfield, Leeds.* Central 158.]

1895. Greensmith, James Eades, Mason Machine Works, Taunton, Massachusetts, United States.

1878. Greenwood, Arthur, Messrs. Greenwood and Batley, Albion Works, Leeds.

1874. Greenwood, William Henry (*Life Member*), Birmingham Metal and Munitions Co., Adderley Park Mills, Birmingham.

1894. Gregory, Horace Mark, Messrs. Brown, Lenox and Co., 9 Martin's Lane, Cannon Street, London, E.C. ; and Ynysyngharad, Pontypridd.

1892. Gresham, Harry Edward, Messrs. Gresham and Craven, Craven Iron Works, Salford, Manchester. [*Brake, Manchester.* 613.]

1880. Gresham, James, Messrs. Gresham and Craven, Craven Iron Works, Salford, Manchester. [*Brake, Manchester.* 613.]

1883. Grew, Frederick, 63 Burnt Ash Hill, Lee, London, S.E.

1895. Griffith, Percy, 54 Parliament Street, Westminster, S.W.

1895. Griffiths, Harry Denis, Manager, Clark's Consolidated, P.O. Box 201, Bulawayo, Rhodesia, South Africa.

1873. Griffiths, John Alfred, Peel Street, South Brisbane, Queensland: (or care of Thomas Griffiths, Langham Road, Bowdon, near Altrincham.)

1889. Grimshaw, James Walter, Resident Engineer, Harbours and Rivers Department, Sydney, New South Wales; and Australian Club, Sydney, New South Wales.

1891. Groom, Richard Alfred, Shropshire Works, Wellington, Salop.

1879. Grose, Arthur, Messrs. Grose Norman and Co., Reliance Works, Northampton.

1886. Grove, David, 24 Friedrich Strasse, Berlin.

1898. Grover, Frederick, Greek Street Chambers, Leeds.

1898. Guest, Charles Henry, General Manager, Messrs. R. W. Webb, Draycott, near Derby. [*Tyre, Draycott.* 1632.]

1884. Gulland, James Ker, Diamond Drill Co., 8 Victoria Street, Westminster, S.W. [*Gulland, London.*]

1870. Gwynne, James Eglinton Anderson (*Life Member*), Brooke Street Works, Holborn, London, E.C. [*Gwynnegram, London.*]

1870. Gwynne, John, Hammersmith Iron Works, Hammersmith, London, W.; and 64 Cannon Street, London, E.C.

1899. Hacking, William Henry, Lord Street, Bury, Lancashire.

1888. Hadfield, Robert Abbott, Hecla Foundry Steel Works, Sheffield. [*Hadfield, Sheffield.*]

1894. Haigh, Noel Newall, Messrs. W. B. Haigh and Co., Globe Iron Works, Plane Street, Oldham.

1897. Haldane, John Wilton Cuninghame, 30 North John Street, Liverpool.

1884. Hall, Albert Francis, George F. Blake Manufacturing Co., Third Street, East Cambridge, Massachusetts; and 3 Cordis Street, Charlestown, Boston, Massachusetts, United States.

1894. Hall, Henry Platt, Messrs. Platt Brothers and Co., Hartford New Works, Oldham.

1881. Hall, John Percy, Carville, Lawrie Park Road, Sydenham, London, S.E.

1882. Hall, John Willim, 71 Temple Row, Birmingham.

1890. Hall, Oscar Standring, Messrs. Robert Hall and Sons, Hope Foundry, Bury, Lancashire; and Park Cottage, Bury, Lancashire.

1874. Hall, Thomas Bernard, 119 Colmore Row, Birmingham; and Ingleside, Sandon Road, Edgbaston, Birmingham. [*Tamar, Birmingham.*]

1871. Hall, William Silver, 9A Tsukiji, Tokyo, Japan: (or care of Messrs. Takata and Co., 88 Bishopsgate Street Within, London, E.C.) [*Silverhall, Tokyo.*]

1889. Hall-Brown, Ebenezer, Messrs. Hall-Brown Buttery and Co., Helen Street Engine Works, Govan, Glasgow. [*Triple, Glasgow.* South Side 1843.]

1880. Hallett, John Harry, 123 Bute Street, Cardiff. [*Consulting, Cardiff.*]

1871. Halpin, Druitt, 17 Victoria Street, Westminster, S.W. [*Halpin, London.* Westminster 75, care of Victoria Chambers Co.]

1898. Halstead, Arthur Frederick, Locomotive Superintendent, Rio Tinto Railway, Huelva, Spain.

1895. Halstead, John Henry, Fremantle, Western Australia; and 24 Alma Road, Birkdale, Southport.

1894. Hamer, Walter, Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton. [*Dobsons, Bolton.*]

1894. Hamilton, Robert, Park Villa, Institution Hill, Singapore, Straits Settlements.

1898. Hammett, John George, Mahalakshini Station Road, Bombay, India.

1899. Hammond, Robert, 64 Victoria Street, Westminster, S.W. [*Hammond, London.* Westminster 495.]

1875. Hammond, Walter John, The Grange, Knockholt, near Sevenoaks.

1886. Hanbury, John James, Edgeley, Walm Lane, Willesden Park, London, N.W.

1899. Hancock, Samuel, Eastern Extension Telegraph Co., Singapore, Straits Settlements.

1896. Handyside, Charles Baird, Messrs. Waterlow and Sons, Finsbury, London, E.C.

1891. Harcourt, Otto Simon Henry, Clarence Iron Works, Leeds.

1894. Harding, James Cooper, Messrs. T. Richardson and Sons, Hartlepool Engine Works, Hartlepool.

1888. Harding, Thomas Walter, Tower Works, Leeds.

1881. Hardingham, George Gatton Melhuish, Clun House, Surrey Street, London, W.C. [*Hardingham, London.*]

1883. Hardy, John George, 13 Riemergasse, Stadt, Vienna.

1869. Harfield, William Horatio, Arundel House, Thames Embankment, London, W.C. [*Harfield, London.*]

1887. Hargraves, Richard, 4 Richmond Terrace, Blackburn.

1887. Hargreaves, John Henry, Messrs. Hick Hargreaves and Co., Soho Iron Works, Crook Street, Bolton.

1888. Harker, William, Messrs. Richard Schram and Co., Cannon Street House, London, E.C. [*Schram, London.*]

1898. Harlock, Edward Baker, Messrs. Brunner, Mond and Co., Middlewich.

1894. Harmer, Oscar, Messrs. Alfred Herbert and Co., Coventry; and Hopedale, Spencer Park, Coventry.

1899. Harrap, George Thomas, 5 Budge Row, Cannon Street, London, E.C.

1891. Harris, Gordon, Messrs. Merryweather and Sons, Fire-Engine Works, Greenwich Road, London, S.E.

1879. Harris, Henry Graham, Messrs. Bramwell and Harris, 5 Great George Street, Westminster, S.W. [*Wellbram, London.* Westminster 60.]

1873. Harris, Richard Henry (*Life Member*), 63 Queen Victoria Street, London, E.C.; and Oak Hill, Surbiton, R.O., near Kingston-on-Thames.

1877. Harris, William Wallington, Messrs. A. M. Perkins and Son, 6 Seaford Street, Regent Square, London, W.C.; and 24 Alexandra Road, Hornsey, London, N.

1898. Harrison, Frank, Messrs. Marshall, Sons and Co., 99 Clive Street, Calcutta, India.

1885. Harrison, Frederick Henry, Lincoln Malleable Iron Works, Lincoln. [*Malleable, Lincoln.*]

1888. Harrison, George, Messrs. D. Young and Co., 11 and 12 Southampton Buildings, London, W.C. [*Junkring, London.* Holborn 893.]

1889. Harrison, Captain Gilbert Harwood, R.E., War Office, Whitehall, London, S.W.

1885. Harrison, Joseph, Royal College of Science, Exhibition Road, South Kensington, London, S.W.

1891. Harrison, Joseph Hutchinson, Messrs. Howson and Harrison, 2 Exchange Place, Middlesbrough; and Clifford Villa, Coatham, Redcar.

1887. Harrison, Thomas Henry, Messrs. Davey Paxman and Co., 78 Queen Victoria Street, London, E.C.

1894. Harrison, William John, Locomotive Superintendent, Cia. Paulista, Rio Claro, São Paulo, Brazil; and 44 Bournemouth Road, Folkestone.

1890. Harrison, William Robert, Burnett Avenue, Scale Lane, Hull. [*Arbitrate, Hull.*]

1883. Hart, Frederick, 36 Prospect Street, Poughkeepsie, New York, United States.

1872. Hartnell, Wilson, Benson's Buildings, Park Row, Leeds.

1892. Harvey, Francis Haniel, Messrs. Harvey and Co., Hayle Foundry, Hayle, Cornwall.

1886. Harvey, John Boyd, North's Navigation Collieries, Tondû, near Bridgend, Glamorganshire.

1883. Harvey, Robert, 1 Palace Gate, London, W.

1897. Harvey, Robert, Managing Director, Messrs. McOnie, Harvey and Co., Scotland Street Engine Works, Glasgow. [*Maconie, Glasgow.* Royal 565.]

1878. Harwood, Robert, Soho Iron Works, Bolton.

1881. Haslam, Sir Alfred Seale, Union Foundry, Derby. [*Zero, Derby.*]

1898. Haslam, William Gilbert, Union Foundry, Derby.

1899. Hatch, William Thomas, Engineer-in-Chief, Metropolitan Asylums Board, Norfolk House, Norfolk Street, Strand, London, W.C.

1885. Hatton, Robert James, Henley's Telegraph Works, North Woolwich, London, E.

1885. Haughton, Thomas James, Constitutional Club, Northumberland Avenue, London, W.C.

1892. Hawkins, Rupert Skelton, Locomotive and Carriage Superintendent. Assam and Bengal Railway, Chittagong, India.

1861. Hawkins, William Bailey, 39 Lombard Street, London, E.C.

1870. Hawksley, Charles, 30 Great George Street, Westminster, S.W.

1891. Hawksley, George William, Brightside Boiler and Engine Works, Savile Street East, Sheffield. [*Hawksley, Sheffield.* 327.]

1882. Hayes, Edward, Watling Works, Stony Stratford. [*Hayes, Stony Stratford.*]

1879. Hayes, John, 55 Steep Hill, Lincoln.

1885. Head, Archibald Potter, Messrs. Jeremiah Head and Son, 47 Victoria Street, Westminster, S.W. [*Principium, London.* Westminster 237]; and Queen's Square, Middlesbrough.

1888. Head, Harold Ellershaw, 23 Rugby Mansions, Addison Bridge, London, W.

1857. Healey, Edward Charles, 33 Norfolk Street, Strand, London, W.C.

1890. Heap, Ray Douglas Theodore, Electrical Engineer's Office, (Waterloo and City Railway), London and South Western Railway, Launcelot Street, London, S.E.

1872. Heap, William, 28 Chapel Street, Liverpool. [*Metal, Liverpool.* Central 809.]

1898. Hearson, Hugh Reginald, 1 The Bund, Shanghai, China.

1898. Heath, Ashton Marler, care of John Carruthers, 13 Victoria Street, Westminster, S.W.

1899. Heath, Elijah Arthur, Messrs. Dick, Kerr and Co., 110 Cannon Street. London, E.C.

1889. Heath, George Wilson, Messrs. Heath and Co., Observatory Works, Crayford, Kent.

1888. Heatly, Harry, Messrs. Heatly and Gresham, 110 Cannon Street, London, E.C.; and Ballygunge, West Hill Road, Wandsworth, London, S.W.

1897. Heaton, Charles, Brades Steel Works, near Birmingham. [*Brades, Birmingham.*]

1897. Heaton, George, Brades Steel Works, near Birmingham. [*Brades, Birmingham.*] (Former Member 1860–1869.)

1899. Hedley, Robert, Works Manager, Tudhoe Iron Works, Spennymoor.

1875. Heenan, Hammersley, Messrs. Heenan and Froude, Newton Heath Iron Works, near Manchester; and The Manor House, Wilmslow, near Manchester. [*Spherical, Newton Heath.*]

1895. Heinke, Edwin Harry Alfred, Locomotive Superintendent, Ferro Carril Mexicano, Orizaba, Mexico: (or care of Miss F. Heinke, The College, Stoke Bishop, near Bristol.)

1879. Hele-Shaw, Henry Selby, LL.D., F.R.S., Professor of Engineering, University College, Liverpool.

1888. Henning, Gustavus Charles, 220 Broadway, New York, United States.

1879. Henriques, Cecil Quixam, Messrs. John H. Wilson and Co., 15 Victoria Street, Westminster, S.W. [*Drague, London.*]

1875. Hepburn, George, Redcross Chambers, Redcross Street, Liverpool. [*Hepburn, Liverpool.*]

1891. Hepburn, Thomas, Officiating Chief Mechanical Engineer, Small Arms Ammunition Factory, Kirkee, Poona, India.

1900. Hepworth, John William, Messrs. Alcock, Ashdown and Co., Bombay, India.

1892. Herbert, Alfred, Machine-Tool Works, Coventry. [*Lathe, Coventry.* 52.]

1893. Herbert, Charles, 35 Queen Victoria Street, London, E.C. [*Mancunian, London.*]

1893. Herbert, George Henry, Messrs. Richard Hornsby and Sons, 75A Queen Victoria Street, London, E.C.

1894. Herman, Benjamin Richard, Messrs. B. R. Herman and Co., McLeod Road, Karachi, India. [*Herman, Karachi.* 47.]

1884. Hernu, Arthur Henry, 69 Victoria Street, Westminster, S.W.

1894. Herriot, William Scott, 11 Rose Hill Street, Derby.

1884. Hervey, Matthew Wilson, Assistant Engineer, West Middlesex Water Works, Hammersmith, London, W.

1879. Hesketh, Everard, Messrs. J. and E. Hall, Iron Works, Dartford. [*Hesketh, Dartford.*]

1897. Hetherington, Edward Palmer, Messrs. John Hetherington and Sons, Vulcan Works, Pollard Street, Manchester.

1872. Hewlett, Alfred, Haseley Manor, Warwick.

1885. Hicken, Thomas, La Compañia Fabricantes Ingleses, 302 Calle Balcarce, Buenos Aires, Argentine Republic: (or care of Miss Hicken, Bourton, near Rugby.)

1896. Higby, Robert George, Sitarampur, Bengal, India.
1894. Higginbottom, Lloyd, Messrs. Higginbottom and Mannock, Crown Iron Works, West Gorton, Manchester.
1879. Higson, Jacob, Crown Buildings, 18 Booth Street, Manchester.
1883. Hill, John Kershaw, Engineer and Manager, West Surrey Water Works, High Street, Walton-on-Thames.
1885. Hill, Robert Anderson, 14 Third Avenue, Hove. Sussex.
1900. Hill, Walter Scott, Engineer R.N., H.M.S. "Leander," Pacific Station.
1890. Hiller, Edward George, Chief Engineer, National Boiler Insurance Co., 22 St. Ann's Square, Manchester.
1882. Hiller, Henry, Consulting Engineer, National Boiler Insurance Co., 22 St. Ann's Square, Manchester; and Athelney, Stanley Road, Alexandra Park, Manchester.
1899. Hiller, Henry King, Engineer, Gas Company, Shanghai, China.
1873. Hilton, Franklin, 45 Talbot Street, Southport.
1898. Hipkins, William Edward, Managing Director, Messrs. James Watt and Co., Soho Foundry, Smethwick, Birmingham.
1897. Hiraoka, Hiroshi, Hiraoka Engineering Works, Honjo, Tokyo, Japan. [*Herocar, Tokyo.*]
1897. Hirst, James, Chief Engineer, Mount Morgan Gold Mining Co., Mount Morgan, Queensland.
1896. Hitchcock, Cyril, District Locomotive Superintendent, North Western Railway, Lahore, Punjaub, India.
1898. Hobbs, Charles James, Hydraulic Engineering Co., 9 Bridge Street, Westminster, S.W.
1891. Hodge, Arthur, Institution of Mining and Metallurgy, Broad Street House, London, E.C.
1891. Hodges, Frank Grattidge, Locomotive Department, Midland Railway, Burton-on-Trent.
1897. Hodges, Frank William, Vauxhall Iron Works, Wandsworth Road, London, S.W.; and Rushmore, Corkran Road, Surbiton.
1896. Hodges, Marcus Henry, Messrs. Hodges Brothers, City Basin Iron Works, Exeter.
1870. Hodges, Petronius, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.
1880. Hodgson, Charles, Messrs. Saxby and Farmer, Railway Signal Works, Canterbury Road, Kilburn, London, N.W. [*Signalmen, London.* Kilburn 421.]
1889. Hodgson, George Herbert, Thornton Road, Bradford.
1899. Hodgson, Henry, Messrs. Scott and Hodgson, Guide Bridge Iron Works, Guide Bridge, near Manchester. [*Engines, Hooley Hill.* 67.]
1892. Hodgson, Henry Edwin, Brookhouse Iron Works, Cleckheaton, S.O. Yorkshire.

1891. Hogarth, Thomas Oswald, Great Western Railway Works, Swindon.

1889. Hoggins, Alfred Farquharson, Brush Electrical Engineering Co., 49 Queen Victoria Street, London, E.C.

1866. Holcroft, Thomas, Bilston Foundry, Bilston.

1886. Holden, James, Locomotive Superintendent, Great Eastern Railway, Stratford Works, London, E.

1899. Holden, Robert, Superintendent Mechanical Engineer, County Borough of West Ham, London, E.; and Birnell House, Canning Town, London, E.

1895. Holgate, Charles Henzell, School Close Works, Leeds.

1895. Holliday, John, Messrs. A. Guinness, Son and Co., St. James' Gate Brewery, Dublin.

1886. Hollis, Charles William, Nottingham Engineering Co., St. Alban's Works, Radford, Nottingham. [*Iron, Nottingham.* Basford 1578.]

1885. Hollis, Henry William, Fairfield, Darlington.

1896. Holman, Frederick, Messrs. N. Holman and Sons, Penzance Foundry, Penzance.

1891. Holman, Hugh Wilson, Messrs. E. J. Caiger and Co., 92 Billiter Buildings, Billiter Street, London, E.C. [*Caiger, London.*]

1899. Holmes, John Henry, Portland Road, Newcastle-on-Tyne.

1896. Holmes, Percy Frederick, Messrs. W. C. Holmes and Co., Whitestone Iron Works and Turnbridge Foundries, Huddersfield. [*Holmes, Huddersfield.* 113.]

1892. Holmström, Carl Albert, care of Swedish and Norwegian Consulate, Shanghai, China: (or care of Messrs. Vickers Sons and Maxim, 28 Victoria Street, Westminster, S.W.)

1883. Holroyd, John, Arncliffe, Downs Road, Luton.

1873. Holt, Henry Percy, 15 Kensington Court, London, W.

1888. Homan, Harold, Messrs. Homan and Rodgers, 10 Marsden Street, Manchester. [*Namoh, Manchester.* 637.]

1895. Homfray, Samuel George, Sir W. G. Armstrong, Whitworth and Co., 8 Great George Street, Westminster, S.W.

1890. Hooker, Benjamin, Pear Tree Court, Farringdon Road, London, E.C.

1892. Hope, John Basil, Locomotive Department, North Eastern Railway, Leeds.

1885. Hopkinson, Charles, Werneth Chambers, 29 Princess Street, Manchester.

1894. Hopkinson, Edward, D.Sc., Messrs. Mather and Platt, Salford Iron Works, Manchester.

1856. Hopkinson, John, Inglewood, St. Margaret's Road, Bowdon, near Altrincham.

1877. Hopkinson, Joseph, Messrs. Joseph Hopkinson and Co., Britannia Works, Huddersfield.

1890. Hopper, Allan, Messrs. William Hopper and Co., Moscow, Russia.

1890. Hopper, James Russell, Messrs. William Hopper and Co., Moscow, Russia.

1889. Hopwood, John, Locomotive Superintendent, Argentine Great Western Railway, Mendoza, Argentine Republic.

1895. Horner, John, Clonard Foundry, Belfast.

1880. Hornsby, James, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham. [*Hornsbys, Grantham.*]

1889. Horsfield, Cooper, Messrs. Holroyd Horsfield and Wilson, Larchfield Foundry, Hunslet Road, Leeds.

1891. Horsfield, Ralph, Messrs. Ralph Horsfield and Co., Bredbury, Woodley, Stockport.

1873. Horsley, Charles, 22 Wharf Road, City Road, London, N.

1892. Horsnell, Daniel, 79 Farringdon Road, London, E.C.

1868. Horton, Enoch, Alma Works, Darlaston, near Wednesbury.

1886. Hosgood, John Howell, Locomotive and Hydraulic Superintendent, Barry Dock and Railways, Barry, near Cardiff.

1899. Hosgood, Octavious Sidney, London and South Wales Engineering Co., Barry Dock, Barry, near Cardiff. [*Bars, Barry.* 41.]

1891. Hosgood, Walter James, Locomotive Department, Port Talbot Railway and Docks, Port Talbot.

1889. Hosken, Richard, care of Messrs. W. Hosken and Co., P.O. Box 667, Johannesburg, Transvaal, South Africa: (or care of J. Hosken, 27 Mincing Lane, London, E.C.)

1866. Houghton, John Campbell Arthur, Sparnon, Torquay.

1898. Houghton, Reginald James, Electrical Copper Co., Ditton Road, Widnes.

1889. Houghton, Thomas Harry, 58 Pitt Street, Sydney, New South Wales: (or care of Messrs. James Simpson and Co., 101 Grosvenor Road, Pimlico, London, S.W.) [*Expansion, Sydney.*]

1887. Houghton-Brown, Ernest, Messrs. Houghton-Brown Brothers, Kingsbury Iron Works, Ballspond, London, N.

1896. House, Henry Alonzo, Bridgeport, Connecticut, United States.

1895. House, Henry Alonzo, Jun., Manager, Liquid Fuel Engineering Co., Columbine Ship Yard, East Cowes, Isle of Wight.

1891. How, William Field, Mutual Life Buildings, George Street, Sydney, New South Wales. [*Alaska, Sydney.*]

1864. Howard, Eliot, Messrs. Hayward Tyler and Co., 90 Whitecross Street, London, E.C.

1897. Howard, Henry Fox, Messrs. Hayward, Tyler and Co., 90 Whitecross Street, London, E.C.

1879. Howard, James Harold, Britannia Iron Works, Bedford; and The Grange, Kempston, Bedford.

1882. Howard, John William, Gloucester Wagon Works, Gloucester.

1896. Howarth, Alfred Montgomery, Railway Construction Department, Public Works Office, Sydney, New South Wales.

1885. Howarth, William, Manager, Oldham Boiler Works, Oldham. [*Boilers, Oldham.*]

1861. Howell, Joseph Bennett, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield [*Howell, Sheffield.*]; and The Tower, Hathersage, near Sheffield.

1877. Howell, Samuel Earnshaw, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield. [*Howell, Sheffield.*]

1892. Howitt, James John, Messrs. Bowman Thompson and Co., Lostock Gralam, Northwich.

1882. Howl, Edmund, Messrs. Lee Howl and Co., Tipton. [*Howl, Tipton.*]

1877. Howlett, Francis, Messrs. Henry Clayton Son and Howlett, Atlas Works, Woodfield Road, Harrow Road, London, W. [*Brickpress, London.*]

1891. Hoy, Henry Albert, Chief Mechanical Engineer, Lancashire and Yorkshire Railway, Horwich, near Bolton.

1887. Hoyle, James Rossiter, Messrs. Thomas Firth and Sons, Norfolk Works, Sheffield.

1891. Hubback, Charles Arbuthnot, Locomotive and Rolling Stock Superintendent, Natal and Nova Cruz Brazilian Railway, Natal, Rio Grande do Norte, Brazil.

1898. Hudson, Francis James, Locomotive Department, Midland Railway, Derby; and 40 West Avenue, Derby.

1882. Hudson, John George, Messrs. Hick Hargreaves and Co., Soho Iron Works, Crook Street, Bolton; and Glenholme, Bromley Cross, Bolton.

1884. Hudson, Robert, Gildersome Foundry, near Leeds [*Gildersome, Leeds.* Central 14.]; and Weetwood Mount, Headingley, near Leeds. [Headingley 4.]

1893. Hudson, William, Ahmedabad, Bombay, India; and 1 Cranworth Street, Stalybridge.

1881. Hughes, Edward William Mackenzie, Managing Director, Hughes' Solid Rolled Axle-Box Co., 53 Victoria Street, Westminster, S.W.; and 1 The Terrace, Thurlow Park Road, West Norwood, London, S.E. [*Sirhind, London.*]

1899. Hughes, George, Locomotive Department, Lancashire and Yorkshire Railway, Horwich, near Bolton.

1867. Hughes, George Douglas, Leen Side Works, Nottingham.

1889. Hughes, John, Messrs. Hughes and Lancaster, 47 Victoria Street, Westminster, S.W.

1891. Hughes, Robert M., Bengal-Nagpur Railway, Chakardharpur, India: (or care of Reginald D. Hughes, 69 Cromford Road, West Hill, London, S.W.)

1897. Hulse, Richard Lamplough, 35 Queen Victoria Street, London, E.C.

1899. Humphrey, Herbert Alfred, Messrs. Brunner, Mond and Co., Northwich.

1866. Humphrys, Robert Harry, Messrs. Humphrys Tennant and Co., Deptford Pier, London, S.E.

1894. Humpidge, James Dickerson, Messrs. Humpidge, Holborow and Co., Dudbridge Iron Works, Stroud, Gloucestershire [*Humpidge, Cainscross.*] ; and Glengar, Frome Park Road, Stroud, Gloucestershire.
1898. Hunt, Robert Woolston, 1137 The Rookery, Chicago, Illinois, United States.
1889. Hunter, Charles Lafayette, Engineer, Bute Docks, Cardiff.
1899. Hunter, George Lewis, Cardiff Railway Co., Tyndall Street, Cardiff.
1886. Hunter, John, Messrs. Campbells and Hunter, Dolphin Foundry, Saynor Road, Hunslet, Leeds.
1877. Hunter, Walter, 17 Victoria Street, Westminster, S.W. [Westminster 75.]
1900. Hurst, Isaac Edwin, Fleet Engineer R.N., H.M.S. "Illustrious," Mediterranean Squadron.
1899. Hutson, Charles Alfred, Messrs. C. A. Hutson and Co., Ceylon Engineering Works, Colombo, Ceylon.
1888. Huxley, George, 20 Mount Street, Manchester.
1885. Hyland, John Frank, Railway Contractor, São Carlos do Pinhal, Estado de São Paulo, Brazil: (or care of Messrs. Lewis and Hyland, New Rents, Ashford, Kent.)

1900. Iddon, James, Brookfield Iron Works, Leyland, near Preston.
1877. Imray, John, Messrs. Abel and Imray, Birkbeck Bank Chambers, Southampton Buildings, London, W.C.
1882. Ingham, William, 31 Whitworth Street, Manchester. [2202.]
1895. Ingham, William, Water Engineer, Torquay.
1888. Ingleby, Joseph, 20 Mount Street, Manchester.
1883. Instone, Thomas, 146 Leadenhall House, Leadenhall Street, London, E.C.
1894. Iorns, Charles Risbee, 145 Cannon Street, London, E.C.
1892. Irons, Thomas, Messrs. Hudson Brothers, Clyde Engineering Works, Granville, New South Wales.
1898. Irwin, Delacherois Hastings, Managing Director, Messrs. Crossley Brothers, Openshaw, Manchester. [*Crossleys, Openshaw.*]
1895. Isaac, Robert, Messrs. Owen, Isaac and Owen, Union Iron Works, Portmadoc. [*Isaac, Portmadoc.*]
1887. Ivatt, Henry Alfred, Locomotive Engineer, Great Northern Railway, Doncaster.
1898. Iveson, Thomas Gill, Locomotive Department, Midland Railway, Derby.

1884. Jacks, Thomas William Moseley, Patent Shaft Works, Wednesbury; and Woodgreen, Wednesbury.
1898. Jackson, Algernon Brooker, 16 Great Tower Street, London, E.C.
1899. Jackson, Sir John, F.R.S.E., 3 Victoria Street, Westminster, S.W.
1895. Jackson, Robert Cattley, 4 Framlington Place, Newcastle-on-Tyne.
1886. Jackson, Thomas, Woodlands View, Horsforth, near Leeds.

1889. Jackson, William, Thorn Grove, Mannofield, Aberdeen.

1876. Jacobs, Charles Mattathias, 88 Bishopsgate Street Within, London, E.C. [*Vexillum, London.*]

1878. Jakeman, Christopher John Wallace, Manager, Messrs. Merryweather and Sons, Tram Locomotive Works, Greenwich Road, London, S.E.

1893. James, Arthur William, Calcutta Landing and Shipping Co., 24 Strand Road, Calcutta, India.

1889. James, Charles William, Alverton House, Croydon Road, Anerley, London, S.E.

1895. James, Christopher William, Messrs. Joshua Buckton and Co., Well House Foundry, Meadow Road, Leeds.

1895. James, Enoch, General Manager, Patent Shaft and Axletree Works, Wednesbury.

1899. James, Herbert Holland, care of Frank James, Silkmore Hall, Stafford.

1889. James, Reginald William, 1 Queen Victoria Street, London, E.C.

1899. James, Thomas, Carriage and Wagon Department, Midland Railway, Derby.

1879. Jameson, George, Messrs. John Jameson and Son, Bow Street Distillery, Dublin.

1881. Jameson, John, Messrs. Jameson and Schaeffer, 2 Akenside Hill, Newcastle-on-Tyne. [*Jameson, Newcastle-on-Tyne.* P.O. 226.]

1888. Jaques, Captain William Henry, 50 Commonwealth Avenue, Boston, Mass., United States.

1888. Jeejeebhoy, Piroshaw Bomanjee, 17 Church Street, Bombay, India.

1880. Jefferies, John Robert, Messrs. Ransomes, Sims and Jefferies, Orwell Works, Ipswich.

1881. Jefferiss, Thomas, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham. [*Tangyes, Birmingham.*]

1877. Jeffreys, Edward Homer, Hawkhills, Chapel Allerton, Leeds.

1893. Jenkin, Charles Frewen, 4 Vanbrugh Park Road West, Blackheath, London, S.E.

1894. Jenkin, Thomas Henry, Messrs. J. Jamieson and Co., Queen's Dock Chambers, Hull. [*Propeller, Hull.* 94.]

1880. Jenkins, Rhys, Patent Office, 25 Southampton Buildings, London, W.C.

1892. Jenkins, William John, Messrs. W. J. Jenkins and Co., Beehive Works, Retford.

1896. Jenkinson, Thomas, Messrs. Pilkington Brothers, Plate Glass Works, St. Helen's, Lancashire.

1893. Jennins, Henry Horwood, Messrs. Edwin Oldroyd and Co., Crown Works, Leeds. [*Calorifics, Leeds.* Central 241.]

1878. Jensen, Peter, 77 Chancery Lane, London, W.C. [*Venture, London.*]

1889. Jessop, George, Messrs. Jessop and Appleby Brothers, London Steam-Crane and Engine Works, Leicester. [*Jessop, Leicester.*]

1885. Johnson, John Clarke, Messrs. James Russell and Sons, Crown Tube Works, Wednesbury.

1890. Johnson, John William, care of Baron L. Knoop, Maison de la Banque des Marchands, Ilyinka, Moscow, Russia.

1891. Johnson, Lacey Robert, Master Mechanic, Pacific Division, Canadian Pacific Railway, Vancouver, British Columbia.

1888. Johnson, Lawrence Potter, Insein, Lower Burma: (or 9 Blackheath Rise, Lewisham, London, S.E.)

1882. Johnson, Samuel, Manager, Globe Cotton and Woollen Machine Works, Rochdale; and Glebelands, Rochdale.

1861. Johnson, Samuel Waite, Locomotive Superintendent, Midland Railway, Derby.

1888. Johnson, William, Castleton Foundry and Engineering Works, Armley Road, Leeds.

1896. Johnston, James, Chief Engineer, Brighton Corporation Water Works, 12 Bond Street, Brighton. [140.]

1895. Johnstone, Captain James Henry L'Estrange, R.E. (*Life Member*), Horse Guards, Whitehall, London, S.W.

1882. Jolin, Philip, 35 Narrow Wine Street, Bristol; and 2 Elmdale Road, Redland, Bristol.

1891. Jones, Charles Frederick, 85 Davenport Street, Bolton.

1871. Jones, Charles Henry, Assistant Locomotive Superintendent, Midland Railway, Derby.

1873. Jones, Edward, Broomfield House, Perry Barr, Birmingham.

1884. Jones, Felix, Messrs. Jones and Foster, 39 Bloomsbury Street, Birmingham.

1878. Jones, Frederick Robert, Superintending Engineer, Sirmoor State, Nahan, near Umballa, Punjaub, India: (or care of Messrs. Richard W. Jones and Co., Newport, Monmouthshire.)

1867. Jones, George Edward, District Locomotive Superintendent, North Western Railway, Sukkur, Scinde, India: (or care of Mrs. H. Jones, Homelea, All Saints' Villas, Cheltenham.)

1878. Jones, Harry Edward, Engineer, Commercial Gas Works, Stepney, London, E.

1881. Jones, Herbert Edward, Locomotive, Carriage and Wagon Superintendent, Cambrian Railways, Oswestry.

1890. Jones, Morlais Glasfryn, 6 Delahay Street, Westminster, S.W.

1882. Jones, Samuel Gilbert, Hatherley Court, Gloucester.

1887. Jones, Thomas, Central Board School, Deansgate, Manchester; and 4 Manley Road, Alexandra Park, Manchester.

1872. Jones, William Richard Sumption, Whitehall Court, London, S.W.

1883. Jordan, Edward, Manager, Cardiff Junction Dry Dock and Engineering Works, Cardiff.

1891. Jordan, Henry George, Jun., Municipal Technical School, Princess Street, Manchester; and 6 Manley Road, Whalley Range, Manchester.

1880. Joy, David, 85 Gracechurch Street, London, E.C.; and 118 Broadhurst Gardens, West Hampstead, London, N.W. (Former Member 1853-1867.)

1891. Judd, Joseph Henry, School Board Offices, Manchester.

1878. Jüngermann, Carl, 9 Nettelbeck Strasse, Berlin, W., Germany.

1884. Justice, Howard Rudulph, 55 and 56 Chancery Lane, London, W.C. [*Syng, London.* Holborn 3.]

1888. Kapteyn, Albert, Westinghouse Brake Co., Canal Road, York Road, King's Cross, London, N.

1899. Kay, George, Queen's Road, Nottingham. [*Kay, Nottingham.* 855.]

1869. Keen, Arthur, London Works, near Birmingham. [*Globe, Birmingham.*]

1883. Keen, Francis Watkins, Patent Nut and Bolt Works, Westbromwich.

1899. Kekewich, George Ormond, Middlesex County Council, Guildhall, Westminster, S.W. [Westminster 218.]

1881. Kendal, Ramsey, Locomotive Department, North Eastern Railway, Darlington.

1879. Kennedy, Professor Alexander Blackie William, LL.D., F.R.S., 17 Victoria Street, Westminster, S.W. [*Kinematic, London.*]

1892. Kennedy, Thomas, The Glenfield Engineering Works, Kilmarnock.

1875. Kenrick, George Hamilton, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich; and Whetstone, Somerset Road, Edgbaston, Birmingham.

1892. Kensington, Frederick, 2 Copthall Buildings, London, E.C.

1866. Kershaw, John, Villa Eugénie-Louise, Boulevard des Moulins, Monte Carlo.

1884. Kershaw, Thomas Edward, Chilvers Coton Foundry, Nuneaton.

1885. Keyworth, Thomas Egerton, Ferro Carril Buenos Aires y Rosario, Campana, Buenos Aires, Argentine Republic: (or care of J. R. H. Keyworth, 28 Grosvenor Road, Birkenhead.)

1885. Kidd, Hector, Colonial Sugar Refining Co., Sydney, New South Wales.

1894. Kiernan, George, Manager, Messrs. Gresham and Craven, Craven Iron Works, Salford, Manchester.

1888. Kikuchi, Kyozo, Superintendent Engineer, Hirano Spinning Mill, Osaka, Japan.

1899. Kilgour, Martin Hamilton, Borough Electrical Engineer, Electric Works Offices, 2 Church Street, Cheltenham.

1895. King, Charles Penrose, Resident Engineer, Epsom Water Works, Epsom.

1897. King, Henry Charles, Great Western Railway Works, Swindon.

1899. King, John James, Foundry Department, Stanton Iron Works, near Nottingham.

1895. King, Thomas Scott, Messrs. Davey Paxman and Co., Standard Iron Works, Colchester.

1872. King, William, Engineer, Liverpool United Gas Works, Duke Street, Liverpool.

1893. Kinghorn, John Warden, care of Messrs. Jardine Matheson and Co., Hong Kong, China.

1877. Kirk, Henry, Messrs. Kirk Brothers and Co., New Yard Iron Works, Workington. [*Kirks, Workington.*]

1884. Kirkaldy, John, 101 Leadenhall Street, London, E.C. [*Compactum, London.*]

1899. Kirkaldy, William George, 99 Southwark Street, London, S.E. [Hop 203.]

1875. Kirkwood, James, care of Commissioner of Customs, Kowloon, Hong Kong. China: (or Grange Park, Prestwick, Ayrshire.)

1859. Kitson, Sir James, Bart., M.P., Monk Bridge Iron Works, Leeds.

1874. Klein, Thorvald, 6 Derby Villas, Forest Hill, London, S.E.

1889. Knap, Conrad, 11 Queen Victoria Street, London, E.C.

1886. Knight, Charles Albert, Babcock and Wilcox Co., 21 Bothwell Street, Glasgow.

1890. Knight, James Percy, Kaiser Steam Tug Co., 27 Great Tower Street, London, E.C. [*Longboat, London.* Avenue 203.]

1896. Kwang, Kwong Yung (*Life Member*), Linsi Colliery; care of the Chinese Engineering and Mining Co., Tientsin, North China.

1898. Lackland, John James, Water Engineer, Town Hall, St. Helens, Lancashire. [69.]

1881. Laing, Arthur, Deptford Shipbuilding Yard, Sunderland.

1883. Lake, William Robert, 45 Southampton Buildings, London, W.C. [*Scopo, London.*]

1897. Lambert, William Fraser, Messrs. G. S. Goodwin and Co., 19 James Street, Liverpool.

1896. Lane, Francis Lawrence, Works Manager, Leeds Forge, Leeds.

1881. Langdon, William, 3 Alexandra Terrace, Exmouth.

1881. Lange, Frederick Montague Townshend, Parliament Mansions, Victoria Street, Westminster, S.W.

1879. Lapage, Richard Herbert, Oakfield, Langley Avenue, Surbiton, London, S.W.

1888. Latham, Baldwin, 13 Victoria Street, Westminster, S.W.; and Duppas House, Old Town, Croydon.

1899. Latta, James Gilmore, 78 Billiter Buildings, London, E.C.

1890. Laurie, Leonard George, Mill Parade, Newport, Monmouthshire.

1867. Lawrence, Henry, 7 and 8 Post Office Chambers, Newcastle-on-Tyne.

1893. Lawrie, James, Assistant Government Marine Surveyor, Singapore, Straits Settlements.

1874. Laws, William George, Borough Engineer and Town Surveyor, Town Hall, Newcastle-on-Tyne; and 65 Osborne Road, Newcastle-on-Tyne. [*Engineer, Newcastle-on-Tyne.*]

1882. Lawson, Frederick William, Messrs. Samuel Lawson and Sons, Hope Foundry, Leeds.

1870. Layborn, Daniel, Messrs. Daniel Layborn and Co., Dutton Street, Liverpool.

1883. Laycock, William S., Victoria Street Works, Sheffield; and Ranmoor, Sheffield. [*Invention, Sheffield.* 907.]

1860. Lea, Henry, Messrs. Henry Lea and Son, 38 Bennett's Hill, Birmingham. [*Engineer, Birmingham.* 113.]

1892. Lea, Richard Henry, Messrs. Lea and Francis, Coventry.

1895. Lea, William Arthur, Compañia de Ferrocarriles del Distrito, Departmento de Construccion, Mexico City, Mexico.

1889. Leaf, Henry Meredith, Burlington Lodge, Streatham Common, London, S.W.

1883. Leavitt, Erasmus Darwin, Jun., 604 Main Street, Cambridgeport, Massachusetts, United States.

1890. Ledingham, John Machray, Royal Laboratory, Royal Arsenal, Woolwich.

1887. Lee, Cuthbert Ridley, Messrs. C. R. Lee and Co., Suffolk House, Laurence Pountney Hill, London, E.C.

1862. Lee, J. C. Frank, 6 Great Winchester Street, London, E.C.

1892. Lee, Richard John, Messrs. Harrison, Lee and Sons, City Foundry, Limerick.

1890. Lee, Samuel Edward, Messrs. Harrison, Lee and Sons, City Foundry, Limerick.

1863. Lees, Samuel, Messrs. H. Lees and Sons, Park Bridge Iron Works, Ashton-under-Lyne.

1889. Legros, Lucien Alphonse, 57 Brook Green, Hammersmith, London, W.

1896. Leisse, George Charles, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1898. Leopard, Charles William, 33 Parkhurst Road, Holloway, London, N.

1878. Lewis, Gilbert, 538 Eccles New Road, Eccles, Manchester.

1895. Lewis, Herbert William, Acting Senior Inspector of Boilers, Custom House, Bombay, India.

1898. Lewis, Joseph Slater, F.R.S.E., General Manager, Messrs. P. R. Jackson and Co., Salford Rolling Mills, Manchester; and Norwood, Ellesmere Park, Eccles. [*Slater Lewis, Eccles.* 34.]

1884. Lewis, Sir William Thomas, Bart., Bute Mineral Estate Office, Aberdare; and Mardy, Aberdare.

1894. Liebert, Henry Anton, Messrs. John Holroyd and Co., Perseverance Works, Milnrow, Rochdale.

1880. Lightfoot, Thomas Bell, Cornwall Buildings, 35 Queen Victoria Street, London, E.C. [*Separator, London.*]; and 7 Eastcombe Villas, Charlton Road, Blackheath, London, S.E.

1891. Lindsay, William Robertson, 7 Ward Road, Dundee.

1890. Lineham, Wilfrid James, Professor of Engineering and Mechanical Science, The Goldsmiths' Institute, New Cross, London, S.E.; and Jesmond, Leyland Road, Lee, London, S.E.

1856. Linn, Alexander Grainger, 121 Upper Parliament Street, Liverpool.

1876. Lishman, Thomas, Mining Engineer, Hetton Colliery, near Fence Houses.

1881. List, John, Superintendent Engineer, Messrs. Donald Currie and Co., Orchard Works, Blackwall, London, E.; and 3 St. John's Park, Blackheath, London, S.E.

1890. Lister, Robert Ramsbottom, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1900. Little, Edwin, Fleet Engineer R.N., H.M.S., "Cæsar," Mediterranean Squadron.

1890. Livens, Frederick Howard, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln.

1900. Liversedge, Henry Thomas, Chief Engineer R.N., The Cottage, Borstal Road, Rochester.

1895. Livingston, James, 30 Great St. Helen's, London, E.C. [*Cinerary, London.*]

1886. Livsey, John Edward, 34 Octavia Street, Battersea, London, S.W.

1867. Lloyd, Charles, 78 Station Road, South Shore, Blackpool.

1854. Lloyd, George Braithwaite (*Life Member*), Edgbaston Grove, Birmingham.

1882. Lloyd, Robert Samuel, Messrs. Hayward Tyler and Co., 90 Whitecross Street, London, E.C.

1894. Lloyd, Sampson Zachary, Managing Director, Engineering Department, Messrs. Nettlefolds, Birmingham [*Nettlefolds, Birmingham.*]; and Areley Hall, Stourport.

1897. Loane, Samuel Joshua, Acting Chief Engineer, Madras Municipality, Municipal Office, Madras, India.

1898. Lobnitz, Fred, Messrs. Lobnitz and Co., Renfrew, near Paisley; and Clarence House, Renfrew, near Paisley.

1879. Lockhart, William Stronach, 67 Granville Park, Blackheath, London, S.E.

1890. Logan, John Walker, Messrs. Davey Paxman and Co., Standard Iron Works, Colchester; and P.O. Box 82, Cape Town, Cape Colony.

1883. Logan, Robert Patrick Tredennick, Engineer's Office, Great Northern Railway of Ireland, Dundalk.

1884. Longbottom, Luke, Locomotive Carriage and Wagon Superintendent, North Staffordshire Railway, Stoke-on-Trent.

1894. Longridge, Captain Cecil Clement, 15 George Street, Mansion House, London, E.C.

1880. Longridge, Michael, Chief Engineer, Engine and Boiler Insurance Co., 12 King Street, Manchester.

1856. Longridge, Robert Bewick, Managing Director, Engine and Boiler Insurance Co., 12 King Street, Manchester; and Yew Tree House, Tabley, near Knutsford.

1875. Longridge, Robert Charles, Kilrie, Knutsford.

1880. Longworth, Daniel, Messrs. Alcock, Ashdown and Co., Mazagon, Bombay, India.

1899. Lonnon, William, Fleet Engineer, R.N., H.M.S. "Agamemnon," Devonport.

1887. Lorrain, James Grieve, Norfolk House, Norfolk Street, London, W.C. [*Lorrain, London.*]

1898. Lotbinière, Captain Alain Chartier Joly de, R.E., Bangalore, Mysore, India.

1888. Low, David Allan, Professor of Engineering, East London Technical College, People's Palace, Mile End Road, London, E.

1885. Low, Robert, Powis Lodge, Vicarage Park, Plumstead.

1884. Lowcock, Arthur, Cloverfield, Whitchurch, Shropshire.

1891. Lowdon, Thomas, Kingsland Crescent, Barry Docks, B.O., near Cardiff.

1873. Lucas, Arthur, 27 Bruton Street, New Bond Street, London, W.

1889. Lucy, Arthur John, Meadowcroft, Penn Road, Croydon.

1897. Lucy, Ernest Edward, Assistant Locomotive Superintendent, Great Western Railway, Stafford Road Works, Wolverhampton.

1886. Lucy, William Theodore, Locomotive Superintendent, North Western Railway, Bahia Blanca, Argentine Republic: (or Thornleigh, Woodstock Road, Oxford.)

1895. Lumsden, Thomas Templeton Mackie, Managing Director, Messrs. James Milne and Son, Milton House Works, Edinburgh.

1898. Lunt, Charles Thomas, Vanguard Cycle Co., Walsall. [*Vanguard, Walsall.* 6075.]

1877. Lupton, Arnold, Professor of Mining Engineering, Yorkshire College, Leeds; and 6 De Grey Road, Leeds. [*Arnold Lupton, Leeds.* Central 330.]

1897. Lupton, Hugh, Messrs. Hathorn, Davey and Co., Sun Foundry, Dewsbury Road, Leeds. [*Hathorn, Leeds.* Central 524.]

1887. Lupton, Kenneth, 6 Jesson Street, Coventry.

1889. Macallan, George, The Cottage, Birchanger, Bishop's Stortford.

1892. Macbean, John James, Messrs. Howarth Erskine and Co., Singapore, Straits Settlements.

1888. Macbeth, John Bruce King, 44 Tamarind Lane, Bombay, India: (or care of Norman Macbeth, Heaton, Bolton.)

1883. Macbeth, Norman, Messrs. John and Edward Wood, Victoria Foundry, Bolton.

1884. MacCarthy, Samuel, Messrs. Lloyd and Lloyd, 90 Cannon Street, London, E.C.; and 18 Adelaide Road, Brockley, London, S.E.

1877. MacColl, Hector, Bloomfield, Belfast.

1897. MacDonald, David Johnstone, South St. Roque's Works, Dundee. [*Medalist, Dundee.* 239.]

1889. Macdonald, James Alexander, Broad Oaks Iron Works, Chesterfield.

1899. MacDonald, John, 146 West Regent Street, Glasgow. [*Consulting, Glasgow.* 298.]

1895. MacGarvey, Howard, Lombard Street Works, Dublin.

1892. Mackay, Charles O'Keefe, Locomotive Department, Lancashire and Yorkshire Railway, Horwich, near Bolton.

1890. Mackay, Joseph, Oriental Avenue, Bangkok, Siam: (or care of Messrs. Barr, Thomson and Co., Kilmarnock.) [*Mackay, Bangkok.*]

1885. MacKenzie, John William, Messrs. Wheatley and MacKenzie, 40 Chancery Lane, London, W.C.; and Northfield, Oxford Road, Upper Teddington, S.O., Middlesex.

1894. Mackie, John, Reading Iron Works, Reading. [*Engineering, Reading.*]

1875. Maclagan, Robert, Blantyre, British Central Africa: (or care of Dr. Maclagan, 9 Cadogan Place, Belgrave Square, London, S.W.)

1889. MacLay, Alexander, Professor of Mechanical Engineering, Glasgow and West of Scotland Technical College, 38 Bath Street, Glasgow.

1886. MacLean, Alexander Scott, Messrs. Alexander Scott and Sons, Sugar Refinery, Berry-yards, Greenock; and 31 Bank Street, Greenock.

1877. MacLellan, John A., Messrs. Alley and MacLellan, Sentinel Works, Polmadie Road, Glasgow. [*Alley, Glasgow.* Royal 673.]

1864. Macnab, Archibald Francis, Tokyo, Japan.

1884. Macpherson, Alexander Sinclair, Messrs. Fairbairn, Naylor, Macpherson and Co., Wellington Foundry, Leeds.

1892. Mactear, James, F.R.S.E., 28 Victoria Street, Westminster, S.W. [*Celestine, London.* Westminster 66.]

1879. Maginnis, James Porter, 9 Carteret Street, Queen Anne's Gate, Westminster, S.W. [*Offsett, London.*]

1891. Mahon, Major Reginald Henry, R.A., Simla, India.

1896. Main, William Henderson, Superintendent, Engine Department, H. M. Mint, Bombay, India.

1873. Mair-Rumley, John George (*Life Member*), 43 Palace Court, London, W. [*Ipsum, London.*]

1884. Mais, Henry Coathupe, 2 Prell's Buildings, Collins and Queen Streets, Melbourne, Victoria.

1898. Maitland, Cree, Locomotive Engineer and Manager, Sungei Ujong Railway, Port Dickson, Singapore, Straits Settlements.

1883. Malan, Ernest de Mérindol, Westinghouse Brake Co., York Road, King's Cross, London, N.

1879. Malcolm, Bowman, Locomotive Engineer, Belfast and Northern Counties Railway, Belfast.

1896. Malloch, William Farquhar, Town Office, Uitenhage, Cape Colony.

1891. Manisty, Edward, Dundalk Iron Works, Dundalk, Ireland; and 24A Bryanston Square, London, W.

1888. Mano, Bunji, Professor of Mechanical Engineering, Imperial University, Tokyo, Japan.

1875. Mansergh, James, 5 Victoria Street, Westminster, S.W.

1894. Mansfield, Edwin, Messrs. Mansfield and Sons, Whitby Engineering Works, near Chester. [*Mansfield, Whitby, Chester.*]

1894. Mansfield, Edwin Albert, Messrs. Mansfield and Sons, Moorgate Station Chambers, London, E.C. [*Luminously, London.*]

1891. Manson, James, Locomotive Superintendent, Glasgow and South Western Railway, Kilmarnock.

1897. Mantle, Harry George, Old Level Iron Works, Brierley Hill. [*Hall, Brierley Hill.* 12,005.]

1893. Manton, Arthur Woodroffe, Whitechapel and Bow Railway, Lansdowne Terrace, 48 Bow Road, London, E.

1862. Mappin, Sir Frederick Thorpe, Bart., M.P., Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield; and Thornbury, Sheffield.

1897. Mapplebeck, Edward, Messrs. John Wilkes, Sons and Mapplebeck, Liverpool Street, Birmingham. [*Wilkes, Birmingham.*]

1878. Marié, Georges, 4 Boulevard des Sablons, Neuilly-sur-Seine, France.

1891. Marks, Edward Charles Robert, 13 Temple Street, Birmingham.

1888. Marks, George Croydon, 18 Southampton Buildings, Chancery Lane, London, W.C. [*Reconstruction, London.*]

1896. Markwick, Alfred Ernest, Superintendent of Machinery, Karachi Municipality, Lawrence Road, Karachi, India.

1884. Marquand, Augustus John, 2 Dock Chambers, Bute Docks, Cardiff. [*Martial, Cardiff.*]

1887. Marriott, William, Engineer and Locomotive Superintendent, Midland and Great Northern Joint Railways, Melton Constable, Norfolk.

1896. Marsh, Douglas Earle, Locomotive Department, Great Northern Railway, Doncaster.

1875. Marshall, Rev. Alfred (*Life Member*), The Vicarage, Feckenham, Redditch.

1865. Marshall, Francis Carr, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne; and Akenside Lodge, Newcastle-on-Tyne.

1890. Marshall, Frank Herbert, Messrs. Wilsons, Pease and Co., Tees Iron Works, Middlesbrough.

1885. Marshall, Henry Dickenson, Messrs. Marshall, Sons and Co., Britannia Iron Works, Gainsborough. [*Marshalls, Gainsborough.* 10.]

1897. Marshall, Herbert, Messrs. Marshall, Sons and Co., Britannia Iron Works, Gainsborough. [*Marshalls, Gainsborough.* 10.]

1871. Marshall, James, Messrs. Marshall, Sons and Co., Britannia Iron Works, Gainsborough. [*Marshalls, Gainsborough.* 10.]

1885. Marshall, Jenner Guest, Norwich Union Chambers, Birmingham; and Westcott Barton Manor, Oxfordshire.

1896. Marshall, Lewis, Messrs. Lumby, Son and Wood, West Grove Works, Halifax. [*Lumby, Halifax.* 5 A.]

1877. Marshall, William Bayley, Richmond Hill, Edgbaston, Birmingham. [*Augustus, Birmingham.*]

1847. Marshall, William Prime, Richmond Hill, Edgbaston, Birmingham. [*Augustus, Birmingham.*]

1899. Marsland, John Samuel, Messrs. Jonas Drake and Son, Ovenden, Halifax.

1859. Marten, Edward Bindon, Pedmore, Stourbridge. [*Marten, Stourbridge.* 8504.]

1881. Martin, Edward Pritchard (*Life Member*), Dowlais Iron Works, Dowlais.

1886. Martin, William Hamilton, Engineering Manager, The Scheldt Royal Shipbuilding and Engineering Works, Flushing, Holland.

1882. Martindale, Warine Ben Hay, 38 Parliament Street, Westminster, S.W.; and Newlands, Ingatestone, Essex.

1884. Massey, George, Post Office Chambers, Pitt Street, Sydney, New South Wales.

1890. Massey, Stephen, Messrs. B. and S. Massey, Openshaw, Manchester.

1893. Massey, William Henry, 25 Queen Anne's Gate, Westminster, S.W.; and Twyford, R.S.O., Berkshire.

1892. Masterton, John Fraser, Locomotive Department, South Eastern Railway, Ashford, Kent.

1899. Mastrantonis, Panayotis, Engine and Boiler Works, Piraeus, Greece.

1894. Mather, George Radford, Messrs. G. R. Mather and Son, Albion Foundry, Wellingborough. [*Mather, Wellingborough.*]

1867. Mather, William, Messrs. Mather and Platt, Salford Iron Works, Manchester. [*Mather, Manchester.*]

1883. Mather, William Penn, Queen Dyeing Co., Providence, Rhode Island, United States.

1882. Matheson, Henry Cripps, Enfield, Sunny Gardens, Hendon, London, N.W.

1891. Mathewson, Jeremiah Eugene, Tilghman's Sand-Blast Co., Broadheath, near Manchester.

1886. Matthews, Robert, Parrs House, Heaton Mersey, near Manchester.

1895. Matthews, Thomas, Imperial Iron and Artesian Well Works, Renshaw Street, West Gorton, Manchester. [*Artesian, Manchester.* 5110.]

1893. Maunsell, Richard Edward Lloyd, Assistant Locomotive Engineer, Great Southern and Western Railway, Inchicore Works, near Dublin.

1873. Maw, William Henry, 35 Bedford Street, Strand, London, W.C. [Gerrard 3663.]

1884. Maxim, Hiram Stevens, Messrs. Vickers, Sons and Maxim, 32 Victoria Street, Westminster, S.W.; and 18 Queen's Gate Place, South Kensington, London, S.W.

1859. Maylor, William, Hanley Grange, Hanley Castle, Worcestershire.

1874. McClean, Frank, Norfolk House, Norfolk Street, Strand, London, W.C.

1898. McCowen, Victor A. H., City Electrical Engineer, Town Hall, Belfast.

1891. McCredie, Arthur Latimer, Mutual Life of New York Buildings, Martin Place, Sydney, New South Wales. [*Ebony, Sydney.* 63.]

1892. McDonald, John, Locomotive Works, Imperial Government Railways, Tokyo, Japan.

1878. McDonald, John Alexander, Assistant Engineer-in-chief, Public Works Department, Perth, Western Australia: (or care of James E. McDonald, 4 Chapel Street, Cripplegate, London, E.C.)

1865. McDonnell, Alexander, 23 Denbigh Street, London, S.W.; and Rydens, Hersham Road, Walton-on-Thames.

1891. McFarlane, George, Sun Insurance Buildings, 121 West George Street, Glasgow. [*Dunsloy, Glasgow.* Royal 3777.]

1895. McFarlane, James, 27 Spring Gardens, Abbeyhill, Edinburgh.

1895. McGee, Walter, Albion Works, Stoney Brae, Paisley. [137.]

1897. McGlashan, William, Chief Mechanical Engineer, Foundry and Shell Factory, Cossipore, Calcutta, India.

1899. McInnes, David Whitton, Messrs. Hayward Brothers and Eckstein, Union Iron Works, Union Street, Borough, London, S.E. [*Hayward Brothers, London.* Hop 193.]

1889. McIntyre, John Henry A., Lecturer on Mechanical Engineering, Allan Glen's School, Glasgow.

1880. McLachlan, John, Messrs. Bow, McLachlan and Co., Thistle Engine Works, Paisley. [*Bow, Paisley.*]

1888. McLaren, Henry, Messrs. J. and H. McLaren, Midland Engine Works, Leeds.

1882. McLaren, Raynes Lauder, 10 Lammas Park Gardens, Ealing, London, W.

1899. McLaren, Richard Andrew, Babcock and Wilcox Co., 147 Queen Victoria Street, London, E.C.

1888. McLarty, Farquhar Matheson, 26 Brougham Street, Greenock. [*Unique, Greenock.*]

1885. McNeil, John, Messrs. Aitken, McNeil and Co., Helen Street, Govan, Glasgow [*Colonial, Glasgow*]; and Rosario, Dalkeith Avenue, Dumbreck, Glasgow.

1896. McPherson, Stewart, Manager, Barnagore Jute Works, Calcutta, India.

1894. McQueen, John, Messrs. John Hetherington and Sons, Vulcan Works, Pollard Street, Manchester.

1891. Meade, Thomas de Courcy, Town Hall, Manchester.

1899. Meaden, Nicholas, Fleet Engineer, R.N., Victoria House, Victoria Street, Rochester.

1882. Meats, John Tempest, Mason Machine Works, Taunton, Massachusetts, United States.

1881. Meik, Charles Scott, care of P. Walter Meik, 16 Victoria Street, Westminster, S.W.

1887. Melhuish, Frederick, Assistant Engineer, Southwark and Vauxhall Water Works, Southwark Bridge Road, London, S.E.

1891. Melville, William Charles, Superintendent Engineer, Liverpool Steam Tug Co., 44 Chapel Street, Liverpool.

1888. Melville, William Wilkie, 42 Carden Road, Peckham, London, S.E.

1897. Mendizabal, Carlos, General Manager, Altos Hornos Iron and Steel Works, Bilbao, Spain.

1878. Menier, Henri, 56 Rue de Châteaudun, Paris.

1897. Meredith, John, Messrs. Turney and Co., Whitemoor Works, Nottingham.

1894. Merrick, Robert, Warren's Place Iron Works, Cork.

1896. Merrifield, Leonard Lancaster, 19 Abingdon Street, Westminster, S.W.

1875. Merryweather, James Compton, Messrs. Merryweather and Sons, Fire-Engine Works, Greenwich Road, London, S.E.; and 4 Whitehall Court, London, S.W. [*Merryweather, London.*]

1891. Metcalfe, Frederick Spencer, Pumping Station, Sewage Works, Burton-on-Trent.

1881. Meysey-Thompson, Arthur Herbert, Messrs. Hathorn Davey and Co., Sun Foundry, Dewsbury Road, Leeds.

1877. Michele, Vitale Domenico de, 8 Queen Anne's Gate, Westminster, S.W.; and Higham Hall, Rochester.

1898. Micklewright, William, Works Manager, Messrs. John Russell and Co., Alma Tube Works, Walsall.

1884. Middleton, Reginald Empson, 17 Victoria Street, Westminster, S.W.

1891. Middleton, Robert, Sheepscar Foundry, Leeds.

1891. Middleton, Robert Thomas, Superintendent of Bridge Works, Bombay, Baroda and Central India Railway, Bombay, India.

1862. Miers, Francis C., Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.; and Eden Cottage, West Wickham Road, Beckenham. [*Foundation, London.* Bank 920.]

1874. Milburn, John, Hawkshead Foundry, Quay Side, Workington.

1893. Millar, Jackson, Messrs. Riley Hargreaves and Co., 11 Merchant Road, Singapore, Straits Settlements: (or care of David Dunlop, 93 Hope Street, Glasgow.)

1889. Miller, Adam, Avondale Lodge, Bull Wood, Dunoon. Argyllshire.

1885. Miller, Harry William, Princess Estate and Gold Mining Co., P.O. Box 1366, Johannesburg, Transvaal, South Africa.

1886. Miller, John Smith, Messrs. Smith Brothers and Co., Hyson Green Works, Nottingham.

1887. Miller, Thomas Lodwick, 7 Tower Buildings N., Water Street, Liverpool.

1893. Milligan, William Scott, Messrs. Pollit and Wigzell, Bank Foundry Sowerby Bridge.

1893. Millington, Frederick Handel, Manager, Patent Pulp Manufacturing Co., Thetford; and Mill House, Thetford.

1885. Millis, Charles Thomas, Principal, Educational Department, Borough Road Polytechnic, London, S.E.

1898. Mills, George Pilkington, Works Manager, Raleigh Cycle Works, Lenton, Nottingham; and The Woodlands, Beeston, Nottingham.

1898. Mills, Richard, Locomotive Department, Midland Railway, Derby; and 9 Wilson Street, Derby.

1897. Mills, William, Atlas Works, Bonner's Field, Sunderland. [*Engineer, Sunderland.* 552.]

1899. Mills, William, Messrs. Morrell and Mills, Trafford Wharf, Salford Docks. Manchester. [*Evaporate, Manchester.*]

1887. Milne, William, Castle Buildings, West Street, Durban, Natal [*Metallic, Durban*]; and The Oaks, 52 Queen Street, Durban, Natal.

1898. Mitchell, George, Manager, Vacuum Brake Co., 32 Queen Victoria Street. London, E.C. [*Solution, London.* Bank 5534.]

1892. Mitcheson, George Arthur, Longton, Staffordshire. [*Mitcheson, Longton.* 4045.]

1899. Mitton, Edward Moss, Jun., Messrs. Ewen and Mitton, Smithfield Works. Sherlock Street, Birmingham. [*Method, Birmingham.*]

1897. Miyabara, Constructor Captain Jiro, Naval Department, Tokyo, Japan.

1870. Moberly, Charles Henry, 33 Bennett Park, Blackheath, London, S.E.

1896. Moffatt, Alexander Charles, Messrs. Moffatt and Eastmead, 39 Victoria Street, Westminster, S.W. [*Hoistway, London.*]

1885. Moir, James, Boyd's Ice Factory, Calicut Street, Bombay, India. [*Frigid, Bombay.*]

1898. Moleeey, Charles Simpson Twigge, Chief Engineer, Colonial Consignment and Distributing Co., Nelson's Wharf, Commercial Road, Lambeth, London, S.E.

1879. Molesworth, Sir Guilford Lindsay, K.C.I.E., The Manor House, Bexley, S.O., Kent.

1881. Molinos, Léon, 48 Rue de Provence, Paris.

1899. Molloy, Harry James, Public Works Department, Tarikere, Mysore, India.

1897. Monkhouse, Edward Wyndham, Messrs. Burstall and Monkhouse, 14 Old Queen Street, Westminster, S.W. [*Advisedly, London.*]

1884. Monroe, Robert, Manager, Penarth Slipway and Engineering Works, Penarth Dock, Penarth.

1898. Moon, Edgar Rupert, Locomotive Superintendent, Midland Railway of Western Australia, Midland Junction Works, Western Australia: (or care of J. E. Moon, Cloudesleigh, Brixton, near Plymouth.)

1876. Moore, Joseph, 1099 Adeline Street, Oakland, San Francisco, California: (or care of Ralph Moore, Government Inspector of Mines, 13 Clairmont Gardens, Glasgow.)

1895. Moore, William James Perry, Worthington Pumping Engine Co., 153 Queen Victoria Street, London, E.C.

1897. Morcom, Alfred, Managing Director, Messrs. Belliss and Morcom, Ledsam Street, Birmingham. [*Belliss, Birmingham.*]

1880. Moreland, Richard, Messrs. Richard Moreland and Son, 3 Old Street, St. Luke's, London, E.C. [*Expansion, London.*]

1889. Morgan, David John, Aberthaw House, Barry, near Cardiff.

1887. Morison, Donald Barns, Messrs. T. Richardson and Sons, Hartlepool Engine Works, Hartlepool.

1896. Morley, Herbert William, Messrs. Cole, Marchent and Morley, Prospect Foundry, Bradford. [*Cole, Bradford.* 690.]

1895. Morrin, Richard, Superintendent Engineer, Messrs. Lamport and Holt, 21 Water Street, Liverpool.

1888. Morris, Charles, Messrs. Jessop and Co., Phœnix Iron Works, Calcutta, India.

1874. Morris, Edmund Legh, New River Water Works, Finsbury Park, London, N.

1890. Morris, Francis Sanders, 4 Trafalgar Square, London, W.C.

1898. Morris, John, Royal Technical Institute, Salford, Manchester.

1890. Morris, John Alfred (*Life Member*), Empire Engineering Co., Empire Works, Failsworth, Manchester.

1900. Morrison, Gabriel James, The Bund, Shanghai, China.

1892. Morton, David Home, 95 Bath Street, Glasgow.

1898. Moulton, Arthur Johnson, Locomotive Department, Midland Railway, Derby.

1858. Mountain, Charles George, 35 Exchange Buildings, Stephenson Place, Birmingham.

1886. Mountain, William Charles, Messrs. Ernest Scott and Mountain, Close Works, Newcastle-on-Tyne [*Esco, Newcastle-on-Tyne.* 1259.]; and South View, Hexham.

1884. Mower, George A. (*Life Member*), Crosby Steam Gage and Valve Co., 75 Queen Victoria Street, London, E.C. [*Crosby, London.*]

1873. Muir, Alfred, Messrs. William Muir and Co., Britannia Works, Sherbourne Street, Strangeways, Manchester.

1876. Muirhead, Richard, 66 Parrock Street, Gravesend.

1890. Mumford, Charles Edward, Messrs. Robert Boby, St. Andrew's Works, Bury St. Edmunds.

1897. Munro, Edward May, Messrs. H. Brecknell, Sons and Munro, Edinburgh Chambers, Baldwin Street, Bristol. [*Brecknell, Bristol.* 467.]

1890. Munro, John, Professor of Mechanical Engineering, Merchant Venturers' Technical College, Unity Street, Bristol.

1890. Munro, Robert Douglas, Chief Engineer, Scottish Boiler Insurance and Engine Inspection Co., 111 Union Street, Glasgow. [*Inspector, Glasgow.* 1271.]

1889. Münster, Bernard Adolph, Engineer, Yokohama, Japan.

1891. Murdoch, Robert Macmillan, Phœnix Metal Die and Engineering Co., 40 Coin Street, Stamford Street, London, S.E.

1890. Murray, Alexander John, Chief Mechanical Engineer, Government Gun-Powder Factory, Kirkee, Bombay, India.

1890. Murray, Kenneth Sutherland, Brin's Oxygen Works, 69 Horseferry Road, Westminster, S.W.

1894. Murray, Thomas Roberts, Managing Director, Messrs. Spencer and Co., Melksham.

1899. Musgrave, John Richard, Messrs. Musgrave Brothers, Crown Point Foundry, East Street, Leeds. [1226.]

1882. Musgrave, Walter Martin, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton. [*Musgrave, Bolton.*]

1897. Musker, Arthur, Messrs. C. and A. Musker, Dundas Street, Bootle, Liverpool. [*Fulgor, Liverpool.* Bootle 104.]

1897. Musker, Charles, Messrs. C. and A. Musker, Dundas Street, Bootle, Liverpool. [*Fulgor, Liverpool.* Bootle 104.]

1888. Myers-Beswick, William Beswick (*Life Member*), 14 Victoria Street, Westminster, S.W.

1899. Nasbey, George William, Managing Director, Messrs. John Lampitt and Co., Vulcan Foundry, Banbury.

1889. Nash, Thomas, Sheffield Testing Works, Blonk Street, Sheffield; and Guzerat House, Nether Edge, Sheffield.

1889. Nasmith, Joseph, 61 Barton Arcade, Manchester.

1888. Nathan, Adolphus, Messrs. Larini Nathan and Co., Milan; and 15 Via Bigli, Milan, Italy.

1896. Naylor, Sam, Messrs. Lumby, Son and Wood, West Grove Works, Halifax. [*Lumby, Halifax.* 5 A.]

1898. Naylor, Tom Hyde, 13 Teresa Terrace, Coatham, Redcar.

1883. Neate, Percy John, 16 The Banks, High Street, Rochester.

1889. Needham, Joseph Edward, Patent Office, 25 Southampton Buildings, London, W.C.

1884. Nelson, John, Contractor's Office, 8 Lendal, York. [*Nelson, York.*]

1895. Nesbit, David Mein, Messrs. Ashwell and Nesbit, 12 Great James Street, Bedford Row, London, W.C. [*Plenum, London.* Holborn 587]; and Victoria Foundry, Leicester.

1890. Newton, Percy, 23 Alexander Square, South Kensington, London, S.W.

1898. Newton, Samuel Barton, Engineer's Office, Midland Railway, Derby.

1897. Newton, Thomas George, Messrs. W. Summerscales and Sons, Chiswell House, 133 Finsbury Pavement, London, E.C.

1884. Nicholls, James Mayne, Locomotive Superintendent, Nitrate Railways, Iquique, Chili.

1884. Nicholson, Henry, care of G. H. Hill, Albert Chambers, Albert Square, Manchester.

1894. Nicholson, John Rumney, Bridgewater Hotel, Worsley, Manchester.

1899. Nicol, Robert Gordon, Harbour Engineer, Harbour Engineer's Office, Aberdeen.

1899. Nisbet, William Holmes, Locomotive Superintendent, Queensland Government Railways, Brisbane, Queensland.

1886. Noakes, Thomas Joseph, Messrs. Thomas Noakes and Sons, 35 and 37 Brick Lane, Whitechapel, London, E.

1884. Noakes, Walter Maplesden, 73 Clarence Street, Wynyard Square, Sydney, New South Wales.

1892. Norris, William, Messrs. Coulthard and Co., Preston.

1868. Norris, William Gregory, Coalbrookdale Iron Works, Coalbrookdale, Shropshire.

1883. North, Gamble, Pisagua, Chile: Queenswood, Eltham: (or 57 Gracechurch Street, London, E.C.)

1878. Northcott, William Henry, General Engine and Boiler Co., Hatcham Iron Works, Pomeroy Street, New Cross Road, London, S.E.; and 6 Earl's Court Square, London, S.W. [*Oxygen, London.*]

1898. Nutt, George Beaumont, Locomotive Superintendent, Beira Railway, Beira, East Africa.

1885. Oakes, Sir Reginald Louis, Bart., Société Anonyme La Métallurgique, 1 Place de Louvain, Bruxelles, Belgium.

1887. O'Brien, Benjamin Thompson, 34 Catharine Street, Liverpool.

1887. O'Brien, John Owden, Messrs. W. P. Thompson and Co., Ducie Buildings, 6 Bank Street, Manchester.

1890. Ockendon, William, Messrs. John Brown and Co., Atlas Steel and Iron Works, Sheffield.

1868. O'Connor, Charles, 20 Lyra Road, Waterloo, Liverpool.

1888. O'Donnell, John Patrick, 70 and 71 Palace Chambers, 9 Bridge Street, Westminster, S.W.; and Fingal, Hemmelton Road, Bromley, Kent. [*ODonnell, London.* Westminster 378.]

1889. Ogden, Fred, Patent Office, 25 Southampton Buildings, London, W.C.

1886. Ogle, Percy John, 4 Bishopsgate Street Within, London, E.C. [*Oglio, London.* Avenue 956.]

1893. Oke, Francis Robert, 5 Coppenhall Terrace, Crewe. [*Oke, Crewe.*]

1875. Okes, John Charles Raymond, 63 Queen Victoria Street, London, E.C. [*Oaktree, London.*]

1899. Oliver, Thomas, North George Street Iron Works, Salford, Manchester.

1882. Orange, James, Messrs. Danby Leigh and Orange, Hong Kong, China: (or care of Mrs. Mary Orange, 2 West End Terrace, Jersey.)

1899. Orcutt, Harry Fred Lee, 145 Cannon Street, London, E.C.

1885. Ormerod, Richard Oliver, 35 Philbeach Gardens, South Kensington, London, S.W.

1899. Ormsby, Alfred Stewart Augustus, Patent Office, Staple Inn, Holborn, London, W.C.

1897. Orr, Charles Roger, Manager, Gourepore Jute Manufacturing and Linseed Crushing Co., Calcutta; and Naihati, Bengal, India.

1899. Osborne, Thomas Peter, Assistant Carriage and Wagon Superintendent, Midland Railway, Derby; and The Chestnuts, Normanton Road, Derby.

1892. Osmond, Frederick John, The Tower, Bagot Street, Birmingham. [*Osmond, Birmingham.* 550.]

1899. Ottewell, Albert, Traffic Street, Derby. [*Ottewell, Derby.* 51.]

1867. Oughterson, George Blake, Broadway House, 2 Broadway, Westminster, S.W.; and 40 Blessington Road, Lewisham, London, S.E.

1897. Outram, Francis Davidson, late R.E., Messrs. Robertson and Outram, 28 Victoria Street, Westminster, S.W. [*Eyebolts, London.*]

1889. Owen, Thomas, Midland Railway, Derby.

1897. Owens, Philip Robert, Messrs. Donaldson and Owens, 73 Drury Buildings, Liverpool. [*Torpedo, Liverpool.*]

1877. Panton, William Henry, Messrs. Dorman Long and Co., Middlesbrough.

1898. Park, Charles Archibald, Carriage Superintendent, London and North Western Railway, Wolverton, R.S.O., Bucks.

1872. Parker, Thomas, Gorton House, Gorton, near Manchester.

1888. Parker, Thomas, Jun., Carriage and Wagon Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester; and Gorton House, Gorton, near Manchester.

1891. Parker, Thomas, F.R.S.E., Manor House, Tettenhall, Wolverhampton. [*Parker, Tettenhall.*]

1899. Parker, Thomas Hugh, Managing Director, Electric Street Car Manufacturing Syndicate, Wolverhampton. [*Autocar, Wolverhampton.*]

1895. Parkinson, Hudson Clough, Engineer's Office, Cumberland Basin, Bristol Docks, Bristol.

1884. Parlane, William, Manager, Hong Kong Ice Company, Hong Kong, China: (or Ladyton Cottage, Bonhill, Dumbartonshire.)

1899. Parrack, William Thomas, Rochester Buildings, 138 Leadenhall Street, London, E.C.

1892. Parratt, William Heather, Rose Hall, Canje Creek, Berbice, British Guiana.

1892. Parrott, Thomas Henry, Fairlight, Westfield Road, Edgbaston, Birmingham.

1886. Parry, Alfred, 12 Inner Temple, Dale Street, Liverpool.

1889. Parry, Evan Henry, Resident Engineer, Wolhuter Gold Mines, P. O. Box 1160, Johannesburg, Transvaal, South Africa.

1878. Parsons, The Hon. Richard Clere, Messrs. Bateman Parsons and Bateman, 39 Victoria Street, Westminster. S.W. [*Outfall, London.*]; and 48 Prince's Gardens, London, S.W.

1886. Passmore, Frank Bailey, Suffolk House, 5 Laurence Pountney Hill, London, E.C. [*Knarf, London.*]

1896. Patchell, William Henry, Engineer-in-chief, Charing Cross and Strand Electricity Supply Corporation, 15 Maiden Lane, Covent Garden, London, W.C.

1900. Paterson, James Alverne, Engineer R.N., H.M.S. "Mohawk," Australian Squadron.

1880. Paterson, Walter Saunders, Bombay Burmah Trading Corporation, Rangoon, British Burmah, India: (or care of Messrs. Wallace Brothers, 8 Austin Friars, London, E.C.)

1877. Paton, John McClure Caldwell, Messrs. Manlove Alliott and Co., Bloomsgrove Works, Ilkeston Road, Nottingham. [*Manloves, Nottingham.*]

1881. Patterson, Anthony, Dowlais Iron Works, Cardiff; and 9 Glossop Terrace, Cardiff.

1883. Pattison, Giovanni, Messrs. C. and T. T. Pattison, Engineering Works, Naples. [*Pattison, Naples.*]

1891. Pattison, Joseph, 123 Bute Street, Cardiff.

1891. Paul, Matthew, Jun., Messrs. Matthew Paul and Co., Levenford Works, Dumbarton.

1872. Paxman, James Noah, Messrs. Davey Paxman and Co., Standard Iron Works, Colchester. [*Paxman, Colchester.*]

1880. Peache, James Courthope, 87 East Hill, Colchester.

1890. Peacock, Francis, Egyptian Delta Light Railway, Damanhour, Lower Egypt.

1890. Peacock, James Albert Wells, Egyptian Delta Light Railway, Damanhour, Lower Egypt.

1869. Peacock, Ralph, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1897. Pearce, Thomas, Managing Director, Messrs. Johns and Waygood, Sturt Street, South Melbourne, Victoria: (or care of Messrs. C. R. Lee and Co., Suffolk House, Laurence Pountney Hill, London, E.C.)

1884. Pearson, Frank Henry, Earle's Shipbuilding and Engineering Works, Hull.

1885. Pearson, Henry William, Engineer, Bristol Water Works, Small Street, Bristol.

1888. Peel, Charles Edmund, Quay Parade, Swansea.

1899. Peet, James, San Fernando, Trinidad, West Indies.

1898. Peet, William Gadsby, Locomotive Department, Midland Railway, Derby.

1900. Pendred, Vaughan, Crohill, Pendennis Road, Streatham, London, S.W.

1897. Penn, Frederick James, Messrs. Westley Richards and Co., Grange Road, Selly Oak, Birmingham.

1873. Penn, John, M.P., 22 Carlton House Terrace, London, S.W.

1873. Penn, William, Messrs. John Penn and Sons, Marine Engineers, Greenwich, London, S.E.

1874. Pepper, Joseph Ellershaw, Clarence Iron Works, Leeds.

1874. Percy, Cornelius McLeod, King Street, Wigan.

1898. Perks, John, Messrs. John Knowles and Co., Wooden Box, Burton-on-Trent.

1898. Pettigrew, William Frank, Locomotive Superintendent, Furness Railway, Barrow-in-Furness.

1893. Philip, William Littlejohn, General Manager, The Mirrlees, Watson and Yaryan Co., Scotland Street, Glasgow; and 7 Sherbrooke Avenue, Pollokshields, Glasgow. [*Mirrlees, Glasgow.*]

1885. Phillips, Charles David, Emlyn Engineering Works, Newport, Monmouthshire. [*Machinery, Newport, Mon.*]

1885. Phillips, Lionel (*Life Member*), Messrs. Wernher, Beit and Co., 120 Bishopsgate Street Within, London, E.C.

1879. Phillips, Robert Edward, 70 Chancery Lane, London, W.C. [*Phicycle, London.* Holborn 1200.]

1890. Phillips, Walter, West India House, Leadenhall Street, London, E.C. [*Philology, London.*]

1882. Phipps, Christopher Edward, Locomotive Superintendent, Madras Railway, Perambore Works, Madras, India.

1894. Pickering, Jonathan, Baltic Chambers, 50 Wellington Street, Glasgow. [6180.]

1876. Piercy, Henry James Taylor, Messrs. Piercy and Co., Broad Street Engine Works, Birmingham. [*Piercy, Birmingham.* 20.]

1877. Pigot, Thomas Francis, 14 Fitzwilliam Place, Dublin.

1888. Pilkington, Herbert, Sheepbridge Iron Works, Chesterfield.

1897. Pilling, Henry, National Boiler Insurance Co., 22 St. Ann's Square, Manchester.

1883. Pillow, Edward, Director of Technical Instruction for Norfolk, Shire Hall, Norwich; and 2 Carlton Terrace, Mill Hill Road, Norwich.

1892. Pinder, Charles Ralph, Broken Hill Chambers, 31 Queen Street, Melbourne, Victoria.

1892. Pirie, George, 3 Church Terrace, Burrage Road, Plumstead.

1888. Pirrie, The Right Hon. William James, LL.D., Messrs. Harland and Wolff, Belfast.

1883. Pitt, Walter, Messrs. Stothert and Pitt, Newark Foundry, Bath. [*Stothert, Bath.*]

1887. Place, John, Messrs. Wheatley Kirk, Price and Co., 49 Queen Victoria Street, London, E.C. [*Indices, London.* Bank 5077.]

1899. Platt, Francis James, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester. [*Atlas, Gloucester.* 58.]

1899. Platt, John, Messrs. Mather and Platt, Salford Iron Works, Manchester; and The Oaklands, Timperley, Altrincham.

1867. Platt, Samuel Radcliffe (*Life Member*), Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1878. Platts, John Joseph, Resident Engineer, Odessa Water Works, Odessa, Russia.

1869. Player, John (*Life Member*), Clydach Foundry, near Swansea.

1892. Pogson, Alfred Lee, care of Messrs. Henry S. King and Co., 65 Cornhill, London, E.C.

1888. Pogson, Joseph, Manager and Engineer, Huddersfield Corporation Tramways, Huddersfield.

1894. Poland, William, Messrs. William Poland and Co., King's Bench Walk, Southwark, London, S.E. [*Determine, London.*]

1893. Pollit, Edward Ernest, Messrs. Pollit and Wigzell, Bank Foundry, Sowerby Bridge.

1894. Pollitt, Harry, Chief Locomotive Engineer, Great Central Railway, Gorton, Manchester. [*Traction, Gorton.*]

1886. Pollock, James, 22 Billiter Street, London, E.C. [*Specific, London.*]

1876. Pooley, Henry, Homestead, Liscard, Cheshire.

1898. Pooley, Henry, Jun., Messrs. Henry Pooley and Son, Albion Foundry, Kidsgrove, Staffordshire.

1899. Pope, Joseph Gordon, Messrs. Bilbie, Hobson and Co., 80 Queen Victoria Street, London, E.C.

1890. Potter, William Henry, Brougham Chambers, Wheeler Gate, Nottingham.

1864. Potts, Benjamin Langford Foster, 55 Chancery Lane, London, W.C.; and 117 Camberwell Grove, London, S.E.

1878. Powel, Henry Coke, Cartref, 3 Winn Road, Burnt Ash Hill, Lee, London, S.E.

1874. Powell, Thomas, Brynteg, Neath.

1891. Powles, Henry Handley Pridham, 90 Oakley Street, Chelsea, London, S.W.

1898. Powrie, William, Messrs. Furnival and Co., 32 St. Bride Street, London, E.C. [*Furnival, London.*]

1867. Pratchitt, John, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.

1865. Pratchitt, William, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.

1892. Pratt, Middleton, 57 Quayside, Newcastle-on-Tyne.

1885. Pratten, William John, Messrs. Harland and Wolff, Belfast.

1890. Preece, Sir William Henry, K.C.B., F.R.S., 13 Queen Anne's Gate, Westminster, S.W.

1882. Presser, Ernest Charles Antoine, Barquillo 26, Madrid.

1897. Price, Charles Edwin, Messrs. Price and Corneille, 112 Grosvenor Road, London, S.W. [*Proclino, London.*]

1877. Price, Henry Sherley, Messrs. Wheatley Kirk, Price, and Co., 49 Queen Victoria Street, London, E.C. [*Indices, London.* Bank 5077.]

1896. Price, James, Harbour Engineer, 9 Lapp's Quay, Cork.

1890. Price, John, Inspecting Engineer, Workington.

1889. Price, John Bennett, 313 Temple Chambers, Brazennose Street, Manchester; and Wyresdale, Wilbraham Road, Chorlton-cum-Hardy, near Manchester.

1859. Price-Williams, Richard, 15 Victoria Street, Westminster, S.W. [*Spandrel, London.*]

1886. Price-Williams, Seymour William, 5 Victoria Street, Westminster, S.W.

1896. Pritchard, Hugh, Dinorwic Slate Quarries, Llanberis, near Carnarvon; and 14 Terfyn Terrace, Port Dinorwic, R.S.O., Carnarvonshire.

1895. Proctor, Charles Faraday, Fittings Department, Edison and Swan Co., Ponders End, London, N.

1894. Pryce, Henry James, Locomotive Superintendent, North London Railway, Bow Road Works, London, E.

1890. Pugh, Charles Henry, Whitworth Works, Rea Street South, Birmingham.

1895. Pugh, Charles Vernon, 34 Spon Street, Coventry.

1887. Pullen, William Wade Fitzherbert, Professor of Mechanical Engineering, South-Western Polytechnic, Manresa Road, Chelsea, London, S.W.; and Fairley Villa, Oxford Road, Putney, London, S.W.

1898. Pulman, Thomas Charles, care of Messrs. Grindlay and Co., Calcutta, India.

1884. Puplett, Samuel, 47 Victoria Street, Westminster, S.W.

1887. Pyne, Sir Thomas Salter, C.S.I., care of H.H. the Ameer of Afghanistan, Kabul: (or care of E. C. Clarke, Foreign Office, Government of India, Simla or Calcutta, India: or care of Edmund Neel, C.I.E., India Office, Whitehall, London, S.W.)

1892. Quentrall, Thomas, H.M. Inspector of Mines, Kimberley, South Africa.

1899. Quin, Robert Cornelius, Electrical and Tramway Engineer, Electricity Works, Blackpool. [*Electricity Works, Blackpool.* 67.]

1870. Radcliffe, William (*Life Member*), Lambcroft, Woodhouse, Sheffield.

1878. Radford, Richard Heber, 15 St. James' Row, Sheffield. [*Radford, Sheffield.*]

1868. Rafarel, Frederic William, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.

1885. Rainforth, William, Britannia Iron Works, Lincoln. [*Rainforths, Lincoln.*]

1878. Rait, Henry Milnes, Messrs. Rait and Gardiner, 155 Fenchurch Street, London, E.C. [*Repairs, London.*]

1892. Ramsay, William, Superintendent Engineer, Scottish Oriental Steamship Co., Hong Kong, China.

1894. Ramsbottom, John Goodfellow, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1898. Ranger, Robert, Messrs. Ind, Coope and Co., Burton-on-Trent.

1860. Ransome, Allen, 304 King's Road, Chelsea, London, S.W. [*Ransome, London.*]

1886. Ransome, James Edward, Messrs. Ransomes, Sims and Jefferies, Orwell Works, Ipswich. [*Ransomes, Ipswich.*]

1888. Rapley, Frederick Harvey, 6 Clement's Lane, Lombard Street, London, E.C.

1889. Ratcliffe, James Thomas, Baumwoll-Manufactur von Izr. K. Poznanski, Lodz, Russian Poland.

1883. Rathbone, Edgar Philip, South African Argosy Association, 18 Bishopsgate Street Within, London, E.C.

1867. Ratliffe, George, 7A Laurence Pountney Hill, London, E.C.

1893. Raven, Vincent Litchfield, Locomotive Department, North Eastern Railway, Darlington.

1883. Reader, Reuben, Phœnix Works, Cremorne Street, Nottingham.

1887. Readhead, Robert, Messrs. John Readhead and Sons, West Docks, South Shields [*Readhead, South Shields.* G.P.O. 14. Nat. 2024.]; and South Garth, South Shields.

1882. Reay, Thomas Purvis, Messrs. Kitson and Co., Airedale Foundry, Leeds.

1881. Redpath, Francis Robert, Canada Sugar Refinery, Montreal, Canada. [*Redpath, Montreal.*]

1883. Reed, Alexander Henry, 64 Mark Lane, London, E.C. [*Wagon, London.*]

1870. Reed, Sir Edward James, K.C.B., F.R.S., Broadway Chambers, Westminster, S.W. [*Carnage, London.*]

1894. Reed, Joseph William, Manager, Engine Works Department, Palmer's Shipbuilding and Iron Works, Jarrow.

1897. Reid, Andrew Thomson, Messrs. Neilson, Reid and Co., Hyde Park Locomotive Works, Glasgow. [*Neilson, Springburn.* Royal 822.]

1891. Reid, Hugh (*Life Member*), Messrs. Neilson, Reid and Co., Hyde Park Locomotive Works, Glasgow. [*Neilson, Springburn.* Royal 822.]

1897. Reid, John (*Life Member*), Messrs. Neilson, Reid and Co., Hyde Park Locomotive Works, Glasgow. [*Neilson, Springburn.* Royal 822.]

1889. Rendell, Alan Wood, Locomotive Superintendent, East Indian Railway, Jamalpur, Bengal, India: (or 42 Goldhurst Terrace, South Hampstead, London, N.W.)

1890. Rendell, Samuel, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester; and New Mills, near Stockport.

1859. Rennie, George Banks, 20 Lowndes Street, Lowndes Square, London, S.W.

1879. Rennie, John Keith, 49 Queen's Gate, London, S.W.

1876. Restler, James William, Engineer, Southwark and Vauxhall Water Works, Southwark Bridge Road, London, S.E.

1883. Reunert, Theodore (*Life Member*), Box 209, Kimberley, South Africa; Box 92, Johannesburg, Transvaal, South Africa: (or care of Messrs. Findlay, Durham and Brodie, 110 Cannon Street, London, E.C.)

1895. Rew, James Henry, Grahamshill House, Airdrie.

1879. Reynolds, George Bernard, care of Messrs. Maclain, Watson and Co., Batavia, Java: (or care of Messrs. Grindlay and Co., 55 Parliament Street, Westminster, S.W.)

1898. Reynolds, William Fleck, Messrs. Travers and Co., Britannia Works, Springfield Road, Belfast.

1890. Rice, Thomas Sydney, Aldermary House, 60 Watling Street, London, E.C. [*Ricto, London.*]

1866. Richards, Edward Windsor, Plâs Llecha, Tredunnock, Caerleon, Monmouthshire.

1897. Richards, Henry William Hall, Messrs. W. Richards and Son, Phœnix Iron Works, Leicester. [*Richards, Leicester.* 89.]

1892. Richardson, Harry Alfred, Messrs. Hick Hargreaves and Co., Soho Iron Works, Crook Street, Bolton.

1865. Richardson, John, Methley Park, near Leeds.

1873. Richardson, John, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1891. Richardson, John Scott, 302 Calle Balcarce, Buenos Aires, Argentine Republic: (or care of J. W. Champness Richardson, Lindum, Pattison Road, Child's Hill, London, N.W.)

1887. Richardson, Sir Thomas, M.P., Messrs. T. Richardson and Sons, Hartlepool Engine Works, Hartlepool.

1874. Riches, Tom Hurry, Locomotive Superintendent, Taff Vale Railway, Cardiff.

1897. Richmond, William Frederick, Shellness, Stradella Road, Herne Hill, London, S.E.

1873. Rickaby, Alfred Austin, Bloomfield Engine Works, Sunderland. [*Rickaby, Sunderland.*]

1899. Ride, Samuel, 85 Royal Exchange, Manchester. [*Elevator, Manchester.*]

1899. Rider, John Hall, Electrical Engineer, Corporation Electricity Works. Plymouth.

1879. Ridley, James Cartmell, Swalwell Steel Works, Newcastle-on-Tyne.

1887. Riekie, John, Deputy Locomotive and Carriage Superintendent, North Western Railway, Lahore, Punjaub, India.

1894. Riley, Joseph Hacking, Elton Iron Works, Bury, Lancashire.

1885. Ripley, Philip Edward, Messrs. Ransomes, Sims and Jefferies, Orwell Works, Ipswich.

1884. Ripper, William, Professor of Mechanical Engineering, Technical Department, University College, St. George's Square, Sheffield.

1879. Rixom, Alfred John, 108 Park Road, Loughborough.

1898. Rixson, Francis, Messrs. Woodhouse and Rixson, Chantrey Steel and Crank Works, Sheffield. [*Rixson, Sheffield.* 1113.]

1899. Roberts, David, General Manager, Messrs. R. Hornsby and Sons, Spittlegate Iron Works, Grantham. [*Hornsbys, Grantham.*]

1891. Roberts, Hugh Jorwerth, Manor House, Breeze Hill, Bootle, Liverpool.

1887. Roberts, Thomas, Locomotive Engineer, Government Railways, Adelaide, South Australia.

1879. Roberts, Thomas Herbert, Superintendent Motive Power, Norfolk and Southern Rail Road, Norfolk, Va., United States.

1887. Roberts, William, 13 Craven Hill Gardens, Hyde Park, London, W.

1892. Robertson, Leslie Stephen, Messrs. Robertson and Outram, 28 Victoria Street, Westminster, S.W. [*Eyebolts, London.*]

1899. Robins, George Mead, Gas and Water Engineer, Sutton, Surrey.

1894. Robinson, Arthur Maurice, Messrs. Thomas Robinson and Son, Railway Works, Rochdale. [*Robinson, Rochdale.*]

1897. Robinson, Charles Arthur, Messrs. Robinson, Sadler and Co., 20 Ebrington Street, Plymouth. [506.]

1894. Robinson, Charles John, Messrs. Thomas Robinson and Son, Railway Works, Rochdale. [*Robinson, Rochdale.*]

1890. Robinson, Frederick Arthur, Messrs. F. A. Robinson and Co., 54 Old Broad Street, London, E.C. [*Farrago, London.*]

1874. Robinson, Henry, Professor of Civil Engineering, King's College, Strand, London, W.C.; and 13 Victoria Street, Westminster, S.W.

1895. Robinson, James, 25 and 27 Leinster Chambers, 4 St. Anne's Square, Manchester.

1898. Robinson, James Armstrong, Stafford Road Works, Great Western Railway, Wolverhampton.

1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Glasgow; and Westwood Hall, near Leek.

1886. Robinson, John, Engineer's Office, New Dock Works, North Eastern Railway, Middlesbrough.

1878. Robinson, John Frederick, Messrs. Sharp Stewart and Co., Atlas Works, Glasgow. [*Loco, Glasgow.* Royal 3210.]

1891. Robinson, John George, Locomotive and Carriage Engineer, Waterford and Limerick Railway, Limerick.

1899. Robinson, Joseph Drinkwater, R.N.R., Superintendent Engineer, Cork Blackrock and Passage Railway, Victoria Road, Cork.

1894. Robinson, Mark Heaton, Messrs. Willans and Robinson, Victoria Works, Rugby [*c/o Willans, Rugby.*]; and Overslade, Rugby.

1890. Robinson, Sydney Jessop, Messrs. W. Jessop and Sons, Brightside Steel Works, Sheffield.

1878. Robinson, Thomas Neild, Messrs. Thomas Robinson and Son, Railway Works, Rochdale. [*Robinson, Rochdale.*]

1895. Robinson, William, Professor of Mechanical and Electrical Engineering, University College, Nottingham.

1897. Robson, George, 14 Union Court, Old Broad Street, London, E.C.

1899. Robson, William Henry, Manager, Messrs. Chance Brothers and Co., near Birmingham.

1891. Roche, Francis James, Grand Junction Gold Mining Co., Waihi, Auckland, New Zealand.

1872. Rofe, Henry, 8 Victoria Street, Westminster, S.W.

1885. Rogers, Henry John, Watford Engineering Works, Watford. [*Mechanical, Watford.* 35.]

1898. Rolfe, John Herbert Hieron, 69 Old Street, London, E.C.

1892. Ronald, Henry, Birmingham Small Arms Co., Small Heath, Birmingham.

1898. Roots, James D., 100 Westminster Bridge Road, London, S.E.
1889. Rosenthal, James Hermann, Babcock and Wilcox Co., 147 Queen Victoria Street, London, E.C.
1881. Ross, William, Messrs. Ross and Walpole, North Wall Iron Works, Dublin. [*Iron, Dublin.* 311.]
1899. Ross, William, Jun., 27 Thistle Street, Glasgow.
1896. Rothery, William Brockbank, Norbriggs, Lytham, R.S.O., Lancashire.
1893. Rounthwaite, Henry Morrison, Messrs. Maudslay Sons and Field, 110 Westminster Bridge Road, London, S.E.; and 15 Nicosia Road, Wandsworth Common, London, S.W.
1856. Rouse, Frederick, Locomotive Department, Great Northern Railway, Peterborough.
1878. Routh, William Pole, Oakfield, Southern Hill, Reading.
1898. Row, Oliver Matthews, Dalham Works, Great Bridgewater Street, Manchester.
1888. Rowan, James, Messrs. David Rowan and Son, Elliot Street, Glasgow.
1892. Rowe, Almond, Senior Government Marine Surveyor, Singapore, Straits Settlements.
1891. Rowland, Bartholomew Richmond, Holly Bank, Altrincham.
1898. Royce, Frederick Henry, Messrs. F. H. Royce and Co., Cooke Street, Hulme, Manchester. [*Switch, Manchester.* 772.]
1885. Ryan, John, D.Sc., Professor of Physics and Engineering, University College, Bristol.

1859. Salt, George, 8 Welbeck Street, Cavendish Square, London, W.
1874. Sampson, James Lyons, Messrs. David Hart and Co., North London Iron Works, Wenlock Road, City Road, London, N. [*Bascule, London.* King's Cross 733.]
1865. Samuelson, The Right Hon. Sir Bernhard, Bart., F.R.S., Britannia Iron Works, Banbury; 56 Prince's Gate, South Kensington, London, S.W.; and Lupton, Brixham, South Devon.
1881. Samuelson, Ernest, Messrs. Samuelson and Co., Britannia Iron Works, Banbury.
1890. Sandberg, Christer Peter, Palace Chambers, Bridge Street, Westminster, S.W.
1899. Sandeman, Edward, Water Engineer, Municipal Offices, Plymouth.
1881. Sanders, Henry Conrad, Messrs. H. G. Sanders and Son, Victoria Works, Victoria Gardens, Notting Hill Gate, London, W.; and Elm Lodge, Southall.
1871. Sanders, Richard David, 5 Kidbrook Grove, Blackheath, London, S.E.
1886. Sandford, Horatio, Messrs. E. A. and H. Sandford, Thames Iron Works, Gravesend.

1881. Sandiford, Charles, Locomotive Superintendent, Uganda Railway, Mombasa.

1891. Sands, Harold, Craythorne, Tenterden, Ashford, Kent.

1894. Sankey, Captain Matthew Henry Phineas Riall, Messrs. Willans and Robinson, Victoria Works, Rugby. [*c/o Willans, Rugby.*]

1899. Sargeant, Edward Frank, Lower Street, Stroud, Gloucestershire. [*Sargeant, Stroud.* 14.]

1900. Sauvage, Edouard, Ingénieur en Chef adjoint du Materiel et de la traction de la Cie. des Chemins de Fer de l'Ouest, 44 Rue de Rome, Paris.

1874. Sauvée, Albert, Union Works, 60 Park Street, Southwark, London, S.E. [*Sovez, London.* Hop 213.]

1891. Savill, Arthur Slater, Exhaust Steam Injector Company, 4 St. Ann's Square, Manchester.

1880. Saxby, John, Messrs. Saxby and Farmer, Railway Signal Works, Canterbury Road, Kilburn, London, N.W. [*Signalmen, London.* Kilburn 421]; and North Court, Hassocks, R.S.O., Sussex.

1893. Saxon, Alfred, Openshaw Engineering Works and Examiner Buildings, Manchester. [959 and 3904.]

1894. Saxon, George, Openshaw Engineering Works and Examiner Buildings, Manchester. [959 and 3904.]

1894. Saxon, James, Openshaw Engineering Works and Examiner Buildings, Manchester. [959 and 3904.]

1869. Scarlett, James, Messrs. E. Green and Son, 2 Exchange Street, Manchester; and Stamford Road, Bowdon, R.O., near Altrincham.

1890. Schofield, George Andrew, General Manager, Sicilian Railways, Palazzo Brijuccia, Palermo, Sicily: (or care of I. D. Schofield, Oakfield, Alderley Edge, Cheshire.)

1886. Scholes, William Henry, 1255 n/n Rivadavia, Buenos Aires, Argentine Republic: (or care of George Scholes, Orwell House, Upton Manor, Plaistow, London, E.)

1883. Schönheyder, William, 4 Rosebery Road, Brixton, London, S.W. [*Schönheyder, London.*]

1890. Schroller, William, 5 Blair Road, Alexandra Park, Manchester.

1886. Schurr, Albert Ebenezer, Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.

1891. Scott, Arthur Forbes, 171 Swan Arcade, Bradford.

1882. Scott, Charles Herbert, Messrs. Summers and Scott, High Orchard Iron Works, Gloucester.

1890. Scott, Frederick McClure, 89 Victoria Street, Liverpool.

1875. Scott, Frederick Whitaker, Atlas Steel and Iron Wire Rope Works, Reddish, Stockport. [*Atlas, Reddish.*]

1891. Scott, Henry John, Glendon Engine Works, Kettering. [*Engine, Kettering.*]

1881. Scott, James, care of Messrs. Reid and Acutt, Smith Street, Durban, Natal: (or Douglasfield, Murthly, Perthshire.)

1886. Scott, James, Consett Iron Works, Consett, R.S.O., County Durham.

1894. Scott, Robert, H. M. Mint, Calcutta, India.

1891. Scott, Robert Julian, Professor of Engineering, New Zealand University, Canterbury College, Christchurch, New Zealand.

1861. Scott, Walter Henry, Great Western of Brazil Railway, Pernambuco, Brazil: (or care of H. Eaton, 75 Tulse Hill, London, S.W.)

1899 Scott, William George, Cheshire Lines Railway, Central Station, Liverpool.

1896. Scriven, Charles, Leeds Old Foundry, Leeds.

1882. Seabrook, Alfred William, 40 Mayfair Avenue, Ilford.

1892. Seaman, Charles Joseph, 134 High Street, Stockton-on-Tees.

1882. Seaton, Albert Edward, Earle's Shipbuilding and Engineering Works, Hull.

1891. Selby, Millin, 2 Rue du Lac, Bruxelles, Belgium.

1882. Selfe, Norman, 279 George Street, Sydney, New South Wales.

1884. Sellers, Coleman, E.D., Professor of Engineering, Stevens Institute, and Franklin Institute; 3301 Baring Street, Philadelphia, Pennsylvania, United States.

1865. Sellers, William, Pennsylvania Avenue, Philadelphia, Pennsylvania, United States.

1896. Sennett, Alfred Richard, The Chalet, Portinscale Road, Putney, London, S.W.

1894. Seymour, Louis Irving, Messrs. H. Eckstein and Co., P.O. Box 149, Johannesburg, Transvaal, South Africa; and Rand Mines, care of Messrs. Maxwell and Earp, P.O. Box 538, Cape Town, Cape Colony.

1883. Shackleford, Arthur Lewis, General Manager, Britannia Railway-Carriage and Wagon Works, Saltley, Birmingham.

1884. Shackleford, William Copley, Manager, Lancaster Wagon Works, Lancaster; and 8 Victoria Street, Westminster, S.W.

1894. Shand, John, Messrs. Bertrams, St. Katherine's Works, Sciennes, Edinburgh.

1884. Shanks, William, Messrs. Thomas Shanks and Co., Johnstone, near Glasgow. [*Shanks, Johnstone.*]

1897. Sharp, John, Bolton Iron and Steel Works, Bolton. [*Hammer, Bolton.* 161.]

1895. Sharp, John Hutchinson, Messrs. Sharp, Stewart and Co., Atlas Works, Glasgow.

1898. Sharp, Sidney, 34 Victoria Street, Westminster, S.W.

1875. Sharp, Thomas Budworth, Consulting Engineer, Muntz Metal Works, Birmingham; and County Chambers A, Martineau Street, Birmingham. [*Budworth, Birmingham.*]

1881. Shaw, Joshua, Messrs. John Shaw and Sons, Wellington Street Works, Salford, Manchester.

1890 Sheldon, Harry Cecil, Messrs. Boult and Wade, 63 Long Row, Nottingham. [*Boult, Nottingham.* 645.]

1900. Sheldon, William John, Resident Engineer, São Paulo Railway, São Paulo, Brazil.

1892. Shepherd, James, Messrs. Joshua Buckton and Co., Well House Foundry, Meadow Road, Leeds.

1861. Shepherd, John, 45 Regent Park Terrace, Headingley, Leeds.

1899. Shepherd, Richard Lillington, Mount Lyell Mining and Railway Co., Queenstown, Tasmania.

1875. Sheppard, Herbert Gurney, Inspector General of Stores, Egyptian State Railways, Gabbari, Alexandria, Egypt: (or 89 Westbourne Terrace, Hyde Park, London, W.)

1876. Shield, Henry, Messrs. Fawcett Preston and Co., Phœnix Foundry, 17 York Street, Liverpool.

1888. Shin, Tsuneta, Director, Ishikawajima Shipbuilding and Engineering Co., Tokyo, Japan.

1892. Shirlaw, Andrew, Suffolk Works, Oozells Street, Birmingham. [*Shirlaw, Birmingham.*]

1889. Shone, Isaac, 47 Victoria Street, Westminster, S.W.

1890. Shoosmith, Harry, Ormiston, Erith, S.O., Kent.

1893. Shroff, Adurjee Burjorjee, Chief Engineer, Sassoon Spinning Mills, Bombay, India.

1885. Shuttleworth, Alfred, Messrs. Clayton and Shuttleworth, Stamp End Works, Lincoln. [*Claytons, Lincoln.*]

1885. Shuttleworth, Major Frank, Messrs. Clayton and Shuttleworth, Stamp End Works, Lincoln; and Old Warden Park, Biggleswade. [*Claytons, Lincoln.*]

1899. Sibbering, George Thomas, Engineer, Taff Vale Railway, Cardiff.

1891. Siemens, Alexander (*Life Member*), 12 Queen Anne's Gate, Westminster, S.W.

1898. Sillar, Arthur Molyneux, 2 Queen Anne's Gate, Westminster, S.W.

1899. Simmance, John Frederick, Messrs. Simmance and Abady, Earl Street Westminster, S.W.

1877. Simonds, William Turner (*Life Member*), Messrs. J. C. Simonds and Son, Oil Mills, Boston.

1876. Simpson, Arthur Telford, Engineer, Chelsea Water Works, 38 Parliament Street, Westminster, S.W.

1883. Simpson, Charles Liddell, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W. [*Aquosity, London.*]

1885. Simpson, James Thomas, Superintending Engineer, Public Works Department, Toungoo, Burma.

1882. Simpson, John Harwood, 1 Hargwyne Street, Brixton, London, S.W.

1891. Sinclair, Russell, Messrs. J. Wildridge and Sinclair, 97 Pitt Street, Sydney, New South Wales.

1881. Sisson, William, Quay Street Iron Works, Gloucester. [*Sisson, Gloucester.*]

1872. Slater, Alfred, Gloucester Wagon Works, Gloucester.

1892. Slight, George Henry, Sub-Director of Lighthouses, Valparaiso, Chile: (or care of George H. Slight, Sen., Waldean, Crofts Lea Park, Ilfracombe.)

1885. Slight, William Hooper, Messrs. W. Henderson and Co., Soerabaya, Java: (or care of G. H. Slight, 64 Cromwell Road, Fitzhugh, Southampton.)

1891. Sloan, Robert Alexander, Messrs. Sloan and Lloyd Barnes, 34 Castle Street, Liverpool. [*Technical, Liverpool.* 6080.]

1886. Small, James Miln, Messrs. Urquhart and Small, 17 Victoria Street, Westminster, S.W.

1897. Smallman, Herbert Spencer, Globe Tube Works, Wednesbury. [*Tubes, Wednesbury.* 6504.]

1900. Smart, Alexander, Erith, S.O., Kent.

1898. Smart, Leslie Sanderson, Locomotive Department, Midland Railway, Gorton, Manchester.

1899. Smeddle, John Henry, Assistant Locomotive Superintendent, North Eastern Railway, Darlington.

1889. Smelt, John Dann, Argentine Great Western Railway, River Plate House, Finsbury Circus, London, E.C. [*Azodnem, London.*]

1899. Smethurst, William, 134 Deansgate, Manchester.

1900. Smith, Alexander Dawson, Mirrlees, Watson and Yaryan Co., 45 Scotland Street, Glasgow.

1860. Smith, Henry, Messrs. Hill and Smith, Brierley Hill Iron Works, Brierley Hill; and Summerhill, Kingswinford, near Dudley. [*Fencing, Brierley Hill.*]

1881. Smith, Henry, Messrs. Simpson and Co., 101 Grosvenor Road, Pimlico, London, S.W.

1898. Smith, Isaac, Messrs. Sydney Smith and Sons, Basford Brass Works, Nottingham; and Mount Hooton House, Nottingham. [*Smiths, Nottingham.* 1537.]

1893. Smith, John, Salford Works, Richard Street, Birmingham. [*Profiler, Birmingham.* 2540.]

1898. Smith, John, Burton Brewery Co., Burton-on-Trent.

1883. Smith, John Bagnold, Westfield House, Sutton-in-Ashfield, Nottingham.

1891. Smith, John Reney, Messrs. H. and C. Grayson, 179 Regent Road, Liverpool.

1898. Smith, John William, Locomotive Department, Midland Railway, Derby.

1890. Smith, John Windle, Messrs. Thomas Drysdale and Co., 438 Calle Moreno, Buenos Aires, Argentine Republic: (or care of Edward Smith, The "Lock," Gainsborough.)

1870. Smith, Michael Holroyd, Royal Insurance Buildings, Crossley Street, Halifax; and 47 Victoria Street, Westminster, S.W. [*Outfall, London.*]

1886. Smith, Reginald Arthur, Messrs. Dorman and Smith, Ordsal Station Electrical Works, Salford, Manchester.

1881. Smith, Professor Robert Henry, 12 Parliament Mansions, Victoria Street, Westminster, S.W.; and Ellerslie, Brunswick Road, Sutton, Surrey.

1897. Smith, Robert Walker, Works Manager, New Enfield Cycle Co., Hunt End Works, Redditch.

1896. Smith, Roger Thomas, 7 Gordon Street, Gordon Square, London, W.C.

1885. Smith, Thomas, Steam Crane Works, Old Foundry, Rodley, near Leeds. [*Tomsmith, Leeds.*]

1898. Smith, Tom Graves, Messrs. Humpidge, Holborow and Co., Dudbridge Iron Works, Stroud, Gloucestershire. [*Humpidge, Cainscross.* 7.]

1898. Smith, Walter Mackersie, Locomotive Department, North Eastern Railway, Gateshead.

1881. Smith, Wasteneys, 59 Sandhill, Newcastle-on-Tyne. [*Wasteneys Smith, Newcastle-on-Tyne.* 2018.]

1890. Smith, William, London and Manchester Plate Glass Co., Sutton, St. Helen's, Lancashire.

1887. Smith, William Mark, District Locomotive Carriage and Wagon Superintendent, Great Southern and Western Railway, Cork.

1884. Smyth, William Stopford, Engineer, Alexandra Docks, Newport, Monmouthshire.

1891. Snell, John Francis Cleverton, Borough Electrical Engineer, Corporation Electricity Station, Sunderland.

1883. Snelus, George James, F.R.S., Ennerdale Hall, Frizington, near Carnforth.

1885. Snowdon, John Armstrong, Stanners Closes Steel Works, Wolsingham, near Darlington.

1897. Snoxell, George Edgar, Birtley Iron Works, Birtley, Durham.

1895. Somers, Walter, Haywood Forge, Halesowen, near Birmingham.

1887. Sorabji, Shapurji, Messrs. Shapurjee and Ratanshaw, 49 Leadenhall Street, London, E.C. [*Ratanshaw, London.*]

1889. Souter-Robertson, David, Assistant Superintendent, Government Canal Foundry and Workshops, Roorkee, North Western Provinces, India.

1885. Southwell, Frederick Charles, Messrs. F. C. Southwell and Co., 75 Southwark Street, London, S.E. [*Prevailing, London.*]

1877. Soyres, Francis Johnstone de, 4 Leicester Place, Clifton, Bristol.

1893. Spence, Arthur William, Manager, Cork Street Foundry and Engineering Works, Dublin.

1898. Spence, Wilfrid L , 50 Melville Street, Pollokshields, Glasgow.

1887. Spence, William, Cork Street Foundry and Engineering Works, Dublin.

1887. Spencer, Alexander, Messrs. George Spencer, Moulton and Co., 77 Cannon Street, London, E.C. [*George Spencer, London.*]

1878. Spencer, Alfred G., Messrs. George Spencer, Moulton and Co., 77 Cannon Street, London, E.C. [*George Spencer, London.*]

1896. Spencer, Charles James, Messrs. Hendry and Pattisson, 4 Marlborough Mews, Hills Place, Oxford Street, London, W.

1892. Spencer, Henry Bath, 48 Downshire Hill, Hampstead, London, N.W.

1877. Spencer, John, Globe Tube Works, Wednesbury; and 14 Great St. Thomas Apostle, London, E.C. [*Tubes, Wednesbury. Tubes, London.* 6504.]

1897. Spencer, John, Atlas Works, Keighley. [*Spencer, Engineer, Keighley.* 118.]

1867. Spencer, John W., Newburn Steel Works, Newcastle-on-Tyne. [*Newburn, Newcastle-on-Tyne.*]

1885. Spencer, Mountford, Messrs. Luke and Spencer, Broadheath, near Manchester; and The Hill, Teignmouth.

1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne. [*Newburn, Newcastle-on-Tyne.*]

1897. Spencer, Thomas Harris, Globe Tube Works, Wednesbury. [*Tubes, Wednesbury.* 6504.]

1891. Spencer, William, Messrs. James Spencer and Co., Chamber Iron Works, Hollinwood, near Manchester.

1885. Spooner, George Percival, 200 Portsdown Road, Maida Vale, London, W.

1883. Spooner, Henry John, Director and Professor of Engineering at the Polytechnic School of Engineering, 309 Regent Street, London, W.

1896. Spring, Francis Joseph Edward, C.I.E., Government Consulting Engineer for Railways, Madras, India.

1869. Stabler, James, 13 Effra Road, Brixton, London, S.W.

1897. Stagg, William, Canons' Marsh Gas Works, Bristol.

1899. Stamer, Arthur Cowie, Locomotive Department, North Eastern Railway, North Road, Darlington.

1877. Stanger, George Hurst, Queen's Chambers, North Street, Wolverhampton.

1875. Stanger, William Harry, Chemical Laboratory and Testing Works, Broadway, Westminster, S.W. [Westminster 117.]

1888. Stanley, Harry Frank, Messrs. H. Pontifex and Sons, Farringdon Works, Shoe Lane, London, E.C.; and 75 Ridge Road, Crouch End, London, N.

1888. Stannah, Joseph, 20 Southwark Bridge Road, London, S.E.
1884. Stanton, Frederic Barry, Mansion House Chambers, 11 Queen Victoria Street, London, E.C.
1897. Steele, James, Works Manager, Messrs. R. Y. Pickering and Co., Wishaw, near Glasgow.
1868. Stephenson, George Robert, Ben Braich, Tilehurst Road, Reading.
1879. Stephenson, Joseph Gurdon Leycester, 6 Drapers' Gardens, London, E.C. [*Fluvius, London.*]
1888. Stephenson-Peach, William John, Askew Hill, Repton, Burton-on-Trent.
1876. Sterne, Louis, Messrs. L. Sterne and Co., Crown Iron Works, Glasgow [*Crown, Glasgow.*]; and Donington House, Norfolk Street, London, W.C. [*Elsterne, London.* Gerrard 1989.]
1898. Stevens, Arthur James, Managing Director, Uskside Iron Works, Newport, Monmonthshire. [*Uskside, Newport, Mon.* P.O. 29; Nat. 53.] (Former Member 1875–1886.)
1891. Stevens, James, 9 and 11 Fenchurch Avenue, London, E.C.
1894. Stevens, Thomas, 110 Northgate Street, Bury St. Edmunds.
1887. Stevenson, David Alan, F.R.S.E., 84 George Street, Edinburgh.
1898. Stevenson, Hew, Messrs. Crompton and Co., Mansion House Buildings, Queen Victoria Street, London, E.C.
1887. Stewart, Andrew, 41 Oswald Street, Glasgow.
1878. Stewart, Duncan, Messrs. Duncan Stewart and Co., London Road Iron Works, Glasgow. [*Stewart, Glasgow.* Royal 531.]
1892. Still, William Henry, Hudjuff, Aden, Arabia.
1880. Stirling, James, Belmore, Ashford, Kent.
1885. Stirling, Matthew, Locomotive Superintendent, Hull Barnsley and West Riding Junction Railway and Dock Co., Hull.
1896. Stirling, Patrick, Great Northern Railway, Doncaster.
1888. Stirling, Robert, care of R. S. Brundell, Redholm, Doncaster.
1898. Stirling, Robert, General Manager, Anglo-Chilian Nitrate and Railway Co., Tocopilla, Chile.
1898. Stobie, George, Government Harbour Department, Durban, Natal.
1893. Stockton, Joseph Sadler, Lyndhurst, Waverley Road, Kenilworth.
1892. Stone, Edward Herbert, Chief Engineer, East Indian Railway, Calcutta, India.
1887. Stone, Frank Holmes, G. P. O., Freetown, Sierra Leone.
1894. Stone, Sidney, Metropolitan Railway-Carriage and Wagon Works, Saltley, Birmingham.
1877. Stothert, George Kelson, Steam Ship Works, Bristol.
1888. Strachan, James, 50 Frederick Street, Gray's Inn Road, London, W.C.
1892. Strachan, John, Craigisla, Penylan, Cardiff.

1888. Straker, Sidney, 110 Cannon Street, London, E.C. [*Rhomboidal, London.* Bank 5200.]; and Marazion, Bromley Hill, Kent.

1897. Strickland, Frederic, 215 Upper Richmond Road, Putney, London, S.W.

1895. Stromeyer, Johann Philipp Edmond Charles, Manchester Steam Users' Association, 9 Mount Street, Manchester.

1884. Stronge, Charles, Locomotive Department, Porto Alegre and New Hamburg Railway, São Leopoldo, Rio Grande do Sol, Brazil.

1899. Stubbs, Joseph Hetherington, Mill Street Works, Ancoats, Manchester. [*Winding, Manchester.*]

1890. Stutzer, Waldemar, Koltchugin Brass and Copper Mill Co., Alexandrov Station, Jaroslav Railroad, Russia.

1882. Sugden, Thomas, Babcock and Wilcox Co., 147 Queen Victoria Street, London, E.C.

1890. Sulzer, Jacob, Messrs. Sulzer Brothers, Winterthur, Switzerland.

1861. Sumner, William, 2 Brazennose Street, Manchester.

1899. Surtees, Henry Wardale, Parker Foundry Co., Derby.

1875. Sutcliffe, Frederic John Ramsbottom, 52 Ash Grove, Bradford.

1883. Sutton, Joseph Walker, 36 Bedford Street, Strand, London, W.C.

1880. Sutton, Thomas, Kirkstall Forge Co., 1 Victoria Street, Westminster, S.W.

1882. Swaine, John, 9 Miles Road, Clifton, Bristol.

1884. Swan, Joseph Wilson, F.R.S., 57 Holborn Viaduct, London, E.C.; and 58 Holland Park, London, W.

1898. Swasey, Ambrose, Messrs. Warner and Swasey, Cleveland, Ohio, United States.

1897. Swinburne, George, 99 Queen Street, Melbourne, Victoria.

1898. Swinburne, James, 82 Victoria Street, Westminster, S.W. [Westminster 292.]

1882. Swinburne, Mark William, Wallsend Brass Works, Newcastle-on-Tyne; and 117 Park Road, Newcastle-on-Tyne. [*Bronze, Wallsend.*]

1864. Swindell, James Swindell Evers, Homer Hill, Cradley, Staffordshire.

1898. Swingler, Alfred, Messrs. Eastwood, Swingler and Co., Victoria and Railway Iron Works, Derby. [*Swingler, Derby.* 150.]

1878. Taite, John Charles, Messrs. Taite and Carlton, 63 Queen Victoria Street, London, E.C. [Bank 618.]; and The Corner House, Shortlands, S.O., Kent.

1875. Tangye, George, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham. [*Tangyes, Birmingham.*]

1889. Tangye, Harold Lincoln, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham.

1861. Tangye, James, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham; and Aviary Cottage, Illogan, near Redruth.

1895. Tannett, John Croysdale, Messrs. Fullerton, Hodgart and Barclay, Vulcan Works, Paisley.

1899. Taplin, John Minter, Vulcan Boiler and General Insurance Co., 68 Elgin Road, Seven Kings, Ilford.

1879. Tartt, William, Maythorn, Blindley Heath, Godstone, near Red Hill.

1876. Taunton, Richard Hobbs, 10 Coleshill Street, Birmingham.

1874. Taylor, Arthur, 21 Victoria Road, Kensington, London, W.

1900. Taylor, Charles Gerald, Engineer R.N., H.M. Dockyard, Halifax, Nova Scotia.

1873. Taylor, John, 324 Mansfield Road, Nottingham.

1884. Taylor, Joseph, Holme Lea, Tatton Road North, Heaton Moor, near Stockport.

1875. Taylor, Joseph Samuel, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham. [*Derwent, Birmingham.*]

1874. Taylor, Percyvale, Messrs. Burthe and Taylor, Paris; and 21 Victoria Road, Kensington, London, W.

1893. Taylor, Robert, Jun., Works Manager, Messrs. Asa Lees and Co., Soho Iron Works, Oldham.

1882. Taylor, Robert Henry, Admiralty Harbour Works, Dover.

1896. Taylor, William Isaac, Messrs. Clarke, Chapman and Co., 50 Fenchurch Street, London, E.C.

1895. Tebbutt, Sidney, Bagenholt, Northlands Road, Southampton.

1864. Tennant, Sir Charles, Bart. (*Life Member*), The Glen, Innerleithen, near Edinburgh.

1882. Terry, Stephen Harding, 17 Victoria Street, Westminster, S.W.

1891. Tetlow, Ernest, Messrs. Tetlow Brothers, Bottoms Iron Works, Hollinwood, near Manchester.

1899. Thackeray, Thomas, Messrs. Vickers, Sons and Maxim, Barrow-in-Furness.

1877. Thom, William, Messrs. Yates and Thom, Canal Foundry, Blackburn.

1889. Thomas, James Donnithorne, 41 Queen Elizabeth's Walk, Stoke Newington, London, N.

1896. Thomas, James Martin, Superintending Engineer, Boston and Dominion Lines of Steamers; 15 Pembroke Road, Bootle, Liverpool.

1867. Thomas, Joseph Lee, 2 Hanover Terrace, Ladbroke Square, Notting Hill, London, W.

1897. Thomas, Lewis Richard, Great Western Railway Works, Swindon; and Eastcourt Lodge, Swindon.

1888. Thomas, Philip Alexander, 71 Aberdare Gardens, West Hampstead, London, N.W.

1864. Thomas, Thomas, 10 Richmond Road, Roath, Cardiff.

1874. Thomas, William Henry, 6 Delahay Street, Westminster, S.W.

1875. Thompson, John, Highfield Boiler Works, Ettingshall, Wolverhampton. [*Boiler, Wolverhampton.*]

1900. Thompson, John Robert, 10 West Twenty-third Street, New York, United States; and Talbot House, Knowle, Bristol.

1883. Thompson, Richard Charles, Messrs. Robert Thompson and Sons, Southwick Shipbuilding Yard, Sunderland.

1887. Thompson, William Phillips, 6 Lord Street, Liverpool.

1900. Thomsett, Frank Dathan, Chief Engineer R.N., H.M.S. "Racoon," East Indies Station.

1900. Thomson, George, Natal Government Harbour Works, Port Natal, South Africa.

1875. Thomson, James McIntyre, Glen Tower, Great Western Road, Glasgow.

1868. Thomson, John, 3 Crown Terrace, Dowanhill, Glasgow.

1899. Thorburn, William, Luchana Mining Co., Apartado 45, Bilbao, Spain. [*Shoolbred, Bilbao.*]

1893. Thornbery, William Henry, 36 Paradise Street, Birmingham. [*Thornbery, Birmingham.*]

1898. Thorneley, William, Works Manager, Great Central Railway, Gorton, Manchester.

1868. Thornewill, Robert, Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent.

1885. Thornley, George, Messrs. Buxton and Thornley, Waterloo Engineering Works, Burton-on-Trent.

1877. Thornton, Frederic William, Hull Hydraulic Power Co., Machell Street, Hull.

1882. Thornton, Hawthorn Robert, Lancashire and Yorkshire Railway, Horwich, near Bolton.

1876. Thornycroft, John Isaac, F.R.S., Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W. [*Thornycroft, London.* 7306.]

1882. Thow, William, Chief Mechanical Engineer, New South Wales Government Railways, Eveleigh, Sydney, New South Wales: (or care of Joseph Meilbek, 13 Victoria Street, Westminster, S.W.)

1900. Thumwood, Lewis Edward, Chief Engineer R.N., H.M.S. "Mohawk," Australian Squadron.

1896. Tickner, Richard, 60 Mintern Street, New North Road, London, N.

1885. Timmermans, François, Managing Director, Société anonyme des Ateliers de la Meuse, Liége, Belgium. [*Société Meuse, Liége.*]

1884. Timmis, Illius Augustus, 2 Great George Street, Westminster, S.W. [*Timmis, London.*]

1890. Titley, Arthur, Beechwood, Hartopp Road, Four Oaks, Sutton Coldfield, near Birmingham.

1875. Tomkins, William Steele, Messrs. Sharp Stewart and Co., Atlas Works, Glasgow; and 28 Victoria Street, Westminster, S.W.

1888. Topple, Charles James, 6 Blendon Terrace, Plumstead Common.

1894. Touch, John Edward, Selborne House, 11 Ironmonger Lane, London, E.C.

1883. Tower, Beauchamp, 5 Queen Anne's Gate, Westminster, S.W.

1889. Towler, Alfred, Messrs. Hathorn Davey and Co., Sun Foundry, Leeds.

1893. Townsend, Major C. Collingwood, R.A., Superintendent, Gun-Carriage Factory, Madras, India.

1890. Trail, John, Marine Superintendent, Knott's Prince Line of Steamers, Newcastle-on-Tyne.

1888. Travis, Henry, Superintending Engineer and Constructor of Shipping to the War Department, Royal Arsenal, Woolwich.

1889. Treharne, Gwilym Alexander, Pontypridd; and Aberdare.

1889. Trenery, William Penrose, Poste Restante, Paris.

1883. Trentham, William Henry, 39 Victoria Street, Westminster, S.W.

1876. Trevithick, Richard Francis, Locomotive and Carriage Superintendent, Japanese Government Railways, Kobe, Japan: (or care of Mrs. Mary Trevithick, The Cliff, Penzance.)

1887. Trier, Frank, Messrs. Brunton and Trier, 1 Great George Street, Westminster, S.W.

1896. Trotter, Alexander Pelham, Board of Trade, 8 Richmond Terrace, Whitehall, London, S.W.

1885. Trueman, Thomas Brynalyn, 6 Tregenna Terrace, St. Ives, Cornwall.

1887. Turnbull, Alexander, Messrs. Alexander Turnbull and Co., St. Mungo Works, Bishopbriggs, Glasgow. [*Valve, Glasgow.* Royal 4394.]

1885. Turnbull, John, Jun., 18 Blythswood Square, Glasgow. [*Turbine, Glasgow.* Douglas 59.]

1894. Turner, Albert, Whitehouse Machine Works, Denton, near Manchester. [*Machines, Denton.* 205.]

1897. Turner, Alfred, Works Manager, Messrs. George Jones, Lionel Street, Birmingham.

1866. Turner, Frederick, Messrs. E. R. and F. Turner, St. Peter's Iron Works, Ipswich. [*Gippeswyk, Ipswich.*]

1882. Turner, Thomas, Messrs. Andrew Barclay, Sons and Co., Caledonia Works, Kilmarnock. [*Barclayson, Kilmarnock.* 10.]

1886. Turner, Tom Newsum, Vulcan Iron Works, Langley Mill, near Nottingham.

1876. Turney, Sir John, Messrs. Turney Brothers, Trent Bridge Leather Works, Nottingham. [*Turney, Nottingham.*]

1899. Turton, William Henry, Royal Gun Factories, Royal Arsenal, Woolwich.

1882. Tweedy, John, Messrs. Wigham Richardson and Co., Newcastle-on-Tyne.

1897. Twelvetrees, Walter Noble, 47 Victoria Street, Westminster, S.W.; and 91 Louisville Road, Tooting, London, S.W.

1856. Tyler, Sir Henry Whatley, K.C.B., Linden House, Highgate Road, London, N.W.

1899. Unsworth, Herbert George, Locomotive Engineer, Rhondda and Swansea Bay Railway, Swansea.

1898. Urie, Robert Wallace, London and South Western Railway, Nine Elms, London, S.W.

1899. Urie, William Montgomerie, Works Manager, Caledonian Railway, St. Rollox, Glasgow.

1898. Urwick, Arthur John, Messrs. J. F. Pease and Co., Railway Signal Works, Worcester.

1880. Valon, William Andrew McIntosh, 140 and 141 Temple Chambers, Temple Avenue, London, E.C.; and Ramsgate. [*Valon, Ramsgate.*]

1895. Van Raalte, Joseph, General Manager, Royal Shipbuilding and Engineering Works, Flushing, Holland. [*Schelde, Flushing.*]

1885. Vaughan, William Henry, Royal Iron Works, West Gorton, Manchester. [*Vaunting, Manchester.* 5106.]

1897. Vaux, Walter, General Manager, Bradford Tramways and Omnibus Co., Northgate, Bradford. [*Omnibus, Bradford.*]

1862. Vavasseur, Josiah, 28 Gravel Lane, Southwark, London, S.E.; and Rothbury, Blackheath Park, London, S.E. [*Exemplar, London.*]

1900. Veen, Vernon Alfred Alexander ter, Engineer R.N., care of Admiralty, Whitehall, London, S.W.

1899. Vernon, Charles Edward, London and India Docks Joint Committee, 109 Leadenhall Street, London, E.C.

1889. Vesian, John Stuart Ellis de, 20 New Bridge Street, Blackfriars, London, E.C. [*Biceps, London.*]

1865. Vickers, Albert, Messrs. Vickers, Sons and Maxim, River Don Works, Sheffield.

1861. Vickers, Thomas Edward, C.B., Messrs. Vickers, Sons and Maxim, River Don Works, Sheffield.

1856. Waddington, John, 35 King William Street, London Bridge, London, E.C. [Bank 518.]

1899. Waddington, Richard, 35 King William Street, London Bridge, London. E.C. [Bank 518.]

1898. Waddle, Hugh William, Managing Director, Waddle Patent Fan and Engineering Co., Llanmore Works, Llanelly.

1882. Wailes, George Herbert, St. Andrews, Watford, Herts.

1898. Wainwright, John William, British Thomson-Houston Co., 83 Cannon Street, London, E.C.

1888. Waister, William Henry, Locomotive and Carriage Running Department, Great Western Railway, Swindon.

1881. Wake, Henry Hay, Engineer to the River Wear Commission, Sunderland.

1882. Wakefield, William, 123 Rathgar Road, Dublin.

1892. Waldron, Patrick Lawrence, R.N.R., Rockville Cottage, Castletown Berehaven, Co. Cork, Ireland; and 24 St. Joseph's Road, Aughrim Street, Dublin.

1898. Walke, Charles Nicholas Eves, Inspector of Steam Boilers, Town Custom House, Bombay, India.

1890. Walkeden, George Henry, Broken Hill Proprietary Co., Port Pirie, South Australia.

1891 Walker, Arthur Tannett, Messrs. Tannett Walker and Co., Goodman Street Works, Hunslet, Leeds.

1898. Walker, Frederic James, General Manager, St. James' and Pall Mall Electric Light Co., Carnaby Street, Golden Square, London, W. [*Licensable, London.* Gerrard 5082.]

1875. Walker, George, 95 Leadenhall Street, London, E.C.

1890. Walker, Henry, 11 Oxford Terrace, Gateshead.

1894. Walker, Henry Claude, Messrs. R. Waygood and Co., Falmouth Road, Great Dover Street, London, S.E. [*Waygood, London.* Hop 760.]

1875. Walker, John Scarisbrick, Messrs. Walker Brothers, Pagefield Iron Works, Wigan; and 41 Leyland Road, Southport. [*Pagefield, Wigan.*]

1884. Walker, Sydney Ferris, Rose Cottage, Bloomfield Crescent, Bath.

1876. Walker, Thomas Ferdinand, Ship's Log Manufacturer, 58 Oxford Street, Birmingham.

1890. Walker, William George, 47 Victoria Street, Westminster, S.W.

1878. Walker, Zaccheus, Jun., Fox Hollies Hall, near Birmingham.

1897. Wall, Charles Henry, General Manager, Belle Vale Steel Tube Works, Halesowen, Birmingham.

1884. Wallace, John, Backworth Collieries, near Newcastle-on-Tyne.

1895. Wallace, Joseph, Tennant's Agency, San Fernando, Trinidad.

1884. Wallau, Frederick Peter, Superintendent Engineer, Union Steam Ship Co., Southampton.

1868. Wallis, Herbert, 239 Drummond Street, Montreal, Canada.

1893. Wallwork, Roughsedge, Union Bridge Iron Works, Charter Street, Manchester.

1891. Walmsley, John, Messrs. J. and P. Coats, Ferguslie Thread Works, Paisley.

1865. Walpole, Thomas, Windsor Lodge, Monkstown, Co. Dublin.

1877. Walton, James, 112 Heathwood Gardens, Old Charlton, Kent.

1881. Warburton, John Seaton, 19 Stanwick Road, West Kensington, London, W.

1882. Ward, Thomas Henry, Mount Pleasant, Fentham Road, Gravelly Hill, Birmingham.

1876. Ward, William Meese, Newton Villa, Claremont Road, Handsworth, R.O., near Birmingham.

1864. Warden, Walter Evers, Phœnix Bolt and Nut Works, Handsworth, R.O., near Birmingham. [*Bolts, Birmingham.*]

1882. Wardle, Edwin, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds. [*Manning, Leeds.*]

1886. Warren, Frank Llewellyn, 73 Breakspears Road, St. John's, London, S.E.

1899. Warren, Frederick Fridlezius, Managing Director, Messrs. Ross and Walpole, North Wall Iron Works, Dublin. [*Iron, Dublin.* 311.]

1885. Warren, Henry John, Jun., Cornwall Boiler Works, Camborne.

1885. Warren, William, York House, Victoria Road, Kensington, London, W.

1897. Warren, William, Works Manager, Southwick Engine Works, near Sunderland.

1889. Warsop, Thomas, Coniston Copper Mines, Coniston, S.O., Lancashire.

1858. Waterhouse, Thomas (*Life Member*), Claremont Place, Sheffield.

1881. Watkins, Alfred, 58 Fenchurch Street, London, E.C.

1890. Watkinson, William Henry, Professor of Motive Power Engineering, Glasgow and West of Scotland Technical College, 38 Bath Street, Glasgow.

1890. Watson, George Coghlan, Manganese Bronze and Brass Co., St. George's Wharf, Deptford, London, S.E.; and Granville House, Bedford Park, Croydon.

1882. Watson, Henry Burnett, Messrs. Henry Watson and Son, High Bridge Works, Newcastle-on-Tyne. [*Watsons, Newcastle-on-Tyne.* 6517.]

1896. Watson, James Falshaw, 15 Shaw Lane, Headingley, Leeds. [*Inspection, Leeds.*]

1897. Watson, John B., Messrs. James Samuelson and Sons, Wallasey Oil Mills, Birkenhead.

1898. Watson, John Warden, 122 Cannon Street, London, E.C.

1897. Watson, Thomas John, 32 Grainger Street West, Newcastle-on-Tyne.

1879. Watson, Sir William Renny, 16 Woodlands Terrace, Glasgow.

1877. Watts, John, 8 Nelson Street, Bristol.

1897. Wearing, John Evenden, Swan Buildings, Edmund Street, Birmingham.

1886. Weatherburn, Robert, Locomotive Manager, Midland Railway Works, Kentish Town, London, N.W.

1894. Webb, Henry, Messrs. Joseph Webb and Co., Irwell Forge and Rolling Mills, Bury, Lancashire.

1884. Webb, Richard George, Messrs. Richardson and Cruddas, Byculla Iron Works, Bombay, India: (or care of Messrs. Richardson and Hewett, 101 Leadenhall Street, London, E.C.)

1890. Webster, John James, 39 Victoria Street, Westminster, S.W.

1887. Webster, William, 6 Oxley Road, Singapore, Straits Settlements.

1891. Weightman, Walter James, Engineer-in-Chief, Nilgiri Railway, Coonoor, Madras, India.

1888. Wellman, Samuel T., Wellman Seaver Engineering Co., New England Building, Cleveland, Ohio, United States.

1898. Wells, George James, 31 Whitworth Street, Manchester.

1882. West, Charles Dickinson, Professor of Mechanical Engineering, Imperial College of Engineering, Tokyo, Japan.

1895. West, Charles Herbert, Messrs. Henry H. West and Son, 5 Castle Street, Liverpool. [*Referee, Liverpool.* Central 5223.]

1898. West, Ernest Henry, Messrs. H. J. West and Co., Stamford Works, Southwark Bridge Road, London, S.E. [*Copperworm, London.* Hop 879.]

1876. West, Henry Hartley, Messrs. Henry H. West and Son, 5 Castle Street, Liverpool. [*Referee, Liverpool.* Central 5223.]

1894. West, James, P.O. Box 3010, Johannesburg, Transvaal, South Africa.

1894. West, John, Albion Iron Works, Miles Platting, Manchester.

1891. West, Leonard, Ravenhead Plate Glass Works, St. Helens, Lancashire.

1874. West, Nicholas James, Messrs. Nicholas J. West and Sons, 186 Gresham House, Old Broad Street, London, E.C. [*Unlapped, London.*]

1877. Western, Charles Robert, Broadway Chambers, Westminster, S.W. [*Donbowes, London.* Westminster 199.]

1877. Western, Maximilian Richard, care of Colonel Western, C.M.G., Broadway Chambers, Westminster, S.W.

1895. Westmacott, Henry Armstrong, Messrs. John Spencer and Sons, Newburn Steel Works, Newcastle-on-Tyne.

1862. Westmacott, Percy Graham Buchanan, Sir W. G. Armstrong, Whitworth and Co., Elswick Engine Works, Newcastle-on-Tyne; and Rose Mount, Sunninghill, Ascot.

1880. Westmoreland, John William Hudson, Lecturer on Engineering, University College, Nottingham.

1888. Weyman, James Edwardes, 11 Richmond Road, Chorlton-cum-Hardy, Manchester.

1900. Whale, George, Locomotive Department, London and North Western Railway, Crewe.

1896. Wheeler, Percy, General Manager, Oldbury Railway-Carriage and Wagon Works, Oldbury, near Birmingham. [*Carriage Co., Oldbury.*]

1898. Wheelock, Jerome, Worcester, Massachusetts, United States.

1898. Whitaker, Alfred, Resident Locomotive Superintendent, Somerset and Dorset Joint Railway, Highbridge, R.S.O., Somersetshire.

1894. Whitby, Arthur George, Homelea, Great Missenden, R.S.O., Bucks.

1882. White, Alfred Edward, Borough Engineer's Office, Town Hall, Hull.

1888. White, Sir William Henry, K.C.B., LL.D., D.Sc., F.R.S., Assistant Controller and Director of Naval Construction, Admiralty, Whitehall, London, S.W.

1890. Whitehouse, Edwin Edward Joseph, Monkbridge Iron Works, Leeds.

1876. Whiteley, William, Holly Mount, Edgerton, Huddersfield.

1891. Whittaker, John, Messrs. William Whittaker and Sons, Sun Iron Works, Oldham.

1897. Whittell, Alfred Leighton, Manager, Union Cotton Mills, Delisle Road. Parel, Bombay, India.

1878. Wicks, Henry, Messrs. Burn and Co., Howrah Iron Works, Howrah, Bengal, India: (or care of John Spencer, 121 West George Street, Glasgow.)

1897. Wicksteed, Charles, Stamford Road Works, Kettering.

1868. Wicksteed, Joseph Hartley, Messrs. Joshua Buckton and Co., Well House Foundry, Meadow Road, Leeds.

1891. Widdowson, John Henry, Britannia Works, Ordsal Lane, Salford, Manchester. [*Taps, Salford.*]

1897. Widdowson, John Henry, Jun., Britannia Works, Ordsal Lane, Salford, Manchester; and 25 Withington Road, Whalley Range, Manchester. [*Taps, Salford.*]

1878. Widmark, Harald Wilhelm, Helsingborgs Mekaniska Verkstad, Helsingborg, Sweden.

1889. Wigham, John Richardson, Messrs. Edmundsons, Stafford Works, 35 Capel Street, Dublin.

1881. Wigzell, Eustace Ernest, Billiter House, Billiter Street, London, E.C. [*Wigzell, London.*]

1886. Wildridge, John, Messrs. J. Wildridge and Sinclair, 97 Pitt Street, Sydney, New South Wales: (or care of R. Wildridge, 48 Craigmaddie Terrace, Sandyford Street, Glasgow.)

1890. Wildy, William Lawrence, 32 Petherton Road, Highbury New Park, London, N.

1892. Wilkinson, Edward R., Harwell House, Fortis Green, Finchley, London, N.

1898. Wilkinson, George, Kirkside, Bilton, Harrogate. [146.]

1893. Williams, Arthur Edward, Resident Engineer, Dagenham Dock, Essex.

1883. Williams, Sir Edward Leader, Engineer, Manchester Ship Canal Co., 41 Spring Gardens, Manchester [*Leader, Manchester.* 688.]; and The Oaks, Altrincham.

1884. Williams, John Begby, Central Marine Engine Works, West Hartlepool.

1885. Williams, Nicholas Thomas, Carn Bosavern, St. Just, R.S.O., Cornwall.

1847. Williams, Richard (*Life Member*), Brunswick House, Wednesbury.

1890. Williams, Thomas David, 16 Lancaster Road, South Norwood, London, S.E.

1881. Williams, William Freke Maxwell, South Hill Bank, Gravesend.

1899. Williams, William Henry, Divisional Locomotive Superintendent, Great Western Railway, Swindon.

1889. Williams, William Walton, Jun., Messrs. J. Lysaght and Co., Gibraltar; and 87 Elspeth Road, New Wandsworth, London, S.W.

1897. Williams, Wyndham Henry, Messrs. Arthur Butler and Co., Mozufferpore, Tirhoot, India.

1896. Williamson, Joseph, São Paulo Railway, São Paulo, Brazil.

1883. Williamson, Richard, Messrs. Richard Williamson and Son, Iron Shipbuilding Yard, Workington; and South Lodge, Cockermouth.

1897. Wills, Frank, Messrs. W. and F. Wills, Perseverance Works, Bridgwater.

1878. Wilson, Sir Alexander, Bart., Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.

1882. Wilson, Alexander Basil, Holywood, Belfast. [*Wilson, Holywood.* 201.]

1899. Wilson, Charles Louis Napoleon, Water Engineer and Surveyor, Town Hall, Bilston.

1884. Wilson, James, Pacha, Chief Engineer of the Daira Sanieh, Egypt: Cairo, Egypt.

1881. Wilson, John, Engineer, Great Eastern Railway, Liverpool Street Station, London, E C. [*Wilson, Eastern, London.*]

1863. Wilson, John Charles, care of Francis J. Dewar, Edinburgh.

1892. Wilson, John Charles Grant, care of Alexander G. Wilson, 100 Llandaff Road, Cardiff.

1890. Wilson, Joseph William, Principal of School of Practical Engineering, Crystal Palace, Sydenham, London, S.E.

1890. Wilson, Robert James, care of Messrs. Thomas Wilson and Co., 10 and 12 Eastcheap, London, E.C.

1873. Wilson, Thomas Sipling, Messrs. Holroyd Horsfield and Wilson, Larchfield Foundry, Hunslet Road, Leeds.

1888. Wilson, Walter Henry, Messrs. Harland and Wolff, Belfast.

1881. Wilson, Wesley William, Araganagh, Ballsbridge, County Dublin.

1897. Wilson, William Campbell, Messrs. Charles Burrell and Sons, St. Nicholas Works, Thetford.

1897. Wilson, William Henry, Newton Avenue, Longsight, Manchester.

1899. Wilson, William Hope, 34 Maxwell Drive, Pollokshields, Glasgow.

1891. Wimshurst, James Edgar, Messrs. William Esplen, Son, and Swainston, Billiter Buildings, 22 Billiter Street, London, E.C.

1890. Winder, Charles Aston, Messrs. Winder Brothers, Royds Works, Attercliffe, Sheffield.

1886. Windsor, Edwin Wells, 1 Rue du Hameau des Brouettes, Rouen, France.

1890. Wingfield, Digby Charles, 61 Parliament Hill Road, Hampstead, London, N.W.

1887. Winmill, George, Locomotive Superintendent, North Western Railway, Lahore, India: (or Harewood, Junction Road, Romford.)

1898. Winn, Charles Reginald, Messrs. Charles Winn and Co., St. Thomas Works, Granville Street, Birmingham. [*Winn, Birmingham.* 366.]

1872. Wise, William Lloyd, 46 Lincoln's Inn Fields, London, W.C. [*Lloyd Wise, London.* Holborn 378.]

1884. Withy, Henry, Messrs. Furness Withy and Co., Middleton Ship Yard, West Hartlepool. [*Withy, West Hartlepool.* 4246.]

1878. Wolfe, John Edward, Sunderland and South Shields Water Co., 16 Fawcett Street, Sunderland.

1888. Wolff, Gustav William, M.P., Messrs. Harland and Wolff, Belfast.

1900. Wollaston, Thomas Roland, 29 Corporation Street, Manchester. [*Parabola, Manchester.*]

1881. Wood, Edward Malcolm, 3 Victoria Street, Westminster, S.W.

1887. Wood, Henry, Messrs. John and Edward Wood, Victoria Foundry, Bolton.

1880. Wood, John Mackworth, Engineer's Department, New River Water Works, Clerkenwell, London, E.C.

1868. Wood, Sir Lindsay, Bart., Southhill, near Chester-le-Street.

1884. Wood, Sidney Prescott, Semaphore Iron Works, Newport, Melbourne, Victoria: (or care of H. W. Little, Messrs. McKenzie and Holland, Vulcan Iron Works, Worcester.)

1898. Wood, Sydney Henry, Gas Light and Coke Works, Beckton, London, E.

1890. Wood, Thomas Royle, care of Samuel Bash, 1663 Avenida Montes de Oca, Buenos Aires, Argentine Republic: (or care of William Wood, 28 Hyde Grove, Chorlton-on-Medlock, Manchester.)

1896. Wood, Walter Chapman, care of Messrs. J. Buchheister and Co., Shanghai, China.

1890. Wood, William, Gas Meter Co., 238 Kingsland Road, London, E.

1882. Woodall, Corbet, Palace Chambers, 9 Bridge Street, Westminster, S.W.

1899. Woodhead, William Richard, 52 Topaz Street, Roath, Cardiff.

1897. Woods, Arthur Robert Thomas, Messrs. James Nelson and Sons, 41 North John Street, Liverpool.

1894. Woods, William Henry, Messrs. Hamilton Woods and Co., Liver Foundry and Engine Works, Ordsal Lane, Salford, Manchester. [*Sluice, Manchester.* 1962.]

1899. Woof, Thomas, Messrs. Alfred Herbert, 7 Leonard Street, Finsbury, London, E.C.

1898. Woollen, Thomas Henry, Managing Director, The New Jointless Rim Co., Arrol Works, Long Acre, Aston, Birmingham. [*Jointless, Birmingham.* 2625.]

1899. Wootton, John, Messrs. Wootton Brothers, Coalville Iron Works, Coalville, Leicester.

1895. Wordingham, Charles Henry, Electric Light Station, Dickinson Street, Manchester.

1887. Worger, Douglas Fitzgerald, Assistant Engineer, Southwark and Vauxhall Water Works, Southwark Bridge Road, London, S.E.

1874. Worsdell, Thomas William, Stonycroft, Arnside, near Carnforth.

1894. Worsdell, Wilson, Locomotive Superintendent, North Eastern Railway, Gateshead.

1877. Worssam, Henry John, Messrs. G. J. Worssam and Son, Wenlock Road, City Road, London, N. [*Massrow, London.* King's Cross 677.]

1886. Worthington, Charles Campbell, Messrs. Henry R. Worthington, Hydraulic Works, 145 Broadway, New York, United States: (or care of the Worthington Pumping Engine Co., 153 Queen Victoria Street, London, E.C.)

1888. Worthington, Edgar, (Secretary), The Institution of Mechanical Engineers, Storey's Gate, St. James's Park, Westminster, S.W.

1860. Worthington, Samuel Barton, Consulting Engineer, 33 Princess Street, Manchester; and Mill Bank, Bowdon, near Altrincham.

1897. Worthington, William Barton, Chief Engineer, Lancashire and Yorkshire Railway, Manchester.

1899. Wotherspoon, James Douglas, Marine Superintendent, Messrs. Franz Rahtkens and Co., Middlesbrough. [*Rahtkens, Middlesbro.*]

1881. Wrench, John Mervyn, Chief Engineer, Indian Midland Railway, Jhansi, N.W. Provinces, India.

1897. Wright, Frederick George, Great Western Railway Works, Swindon.

1876. Wright, James, Messrs. Ashmore Benson Pease and Co., 181 Queen Victoria Street, London, E.C.

1867. Wright, John Roper, Messrs. Wright Butler and Co., Elba Steel Works, Gower Road, near Swansea.

1859. Wright, Joseph, Metropolitan Railway-Carriage and Wagon Co., Saltley Works, Birmingham; and The Gresham Club, London, E.C.

1895. Wright, William, 16 Great George Street, Westminster, S.W.; and Dudley House, 10 St. John's Hill Grove, New Wandsworth, London, S.W.

1871. Wrightson, Thomas, M.P., Messrs. Head Wrightson and Co., Teesdale Iron Works, Stockton-on-Tees.

1891. Wroe, Joseph, 26 Park Avenue, Manchester, S.E.

1865. Wyllie, Andrew, 1 Leicester Street, Southport.

1877. Wyvill, Frederic Christopher, 19 East Parade, Leeds.

1889. Yarrow, Alfred Fernandez, Isle of Dogs, Poplar, London, E.

1895. Yarwood, William James, Castle Dock Yard, Northwich. [74.]

1899. Yates, Joseph, Managing Director, Messrs. Matthews and Yates, Cyclone Works, Swinton, near Manchester. [*Cyclone, Swinton, Manchester.* 1871.]

1881. Yates, Louis Edmund Hasselts, Deputy Locomotive and Carriage Superintendent, North Western Railway, Lahore, India: (or care of Rev. H. W. Yates, 98 Lansdowne Place, Brighton.)

1899. Yates, Walter, Managing Director, Messrs. Matthews and Yates, Cyclone Works, Swinton, near Manchester. [*Cyclone, Swinton, Manchester.* 1871.]

1880. York, Francis Colin, Locomotive Superintendent, Buenos Aires and Pacific Railway, Junin, Buenos Aires, Argentine Republic: (or care of W. Hannay, 18 Portland Street, Leamington.)

1879. Young, George Scholey, Engineer, Thames Engineering Works, late Messrs. John Penn and Sons, Greenwich, London, S.E.

1874. Young, James, 4 Granville Road, Newcastle-on-Tyne. [*Aid, Newcastle-on-Tyne.*]

1879. Young, James, Salroyd, Thornlaw Road, West Norwood, London, S.E.

1892. Young, Robert, Engineer and Manager, Penang Steam Tramways, Penang, Straits Settlements.

1894. Young, Smelter Joseph, The Tempered Spring Co., Limited, Rockingham Street, Sheffield. [*Tempered, Sheffield.* 354.]

1899. Young, Thomas, 4 West Regent Street, Glasgow.

1887. Young, William Andrew, Messrs. Lobnitz and Co., Renfrew, near Paisley [*Lobnitz, Renfrew.* 57, *Paisley.*]; and Millburn House, Renfrew, near Paisley.

1881. Younger, Robert, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

ASSOCIATE MEMBERS.

1896. Abady, Jacques, Messrs. Alexander Wright and Co., 81 Page Street, Westminster, S.W. [*Precision, London.* Westminster 337.]

1896. Abella, Juan, Director General of Public Lighting, 691 Calle Bolivar, Buenos Aires, Argentine Republic.

1898. Acfield, Wilfred Cosens, London Brighton and South Coast Railway, London Bridge, London, S.E.

1896. Adams, George, 55 Victoria Street, Westminster, S.W.

1892. Adams, Sidney Rickman, P.O. Box 2221, Johannesburg, Transvaal, South Africa: (or care of Henry Adams, 3 Colville Square, Bayswater, London, W.)

1898. Adiassewich, Alexander Victorovitch, 5 Fen Court, London, E.C.

1899. Alder, George Frederick, Manager, Oldbury Works, Tewkesbury.

1890. Alderson, George Alexander, Messrs. Allen, Alderson and Co., Alexandria, Egypt; and The Cloisters, Bulkeley, Alexandria, Egypt.

1899. Alexander, Joseph George, Borough Engineer's Office, Town Hall, Wolverhampton.

1897. Allen, Justin Edward, Superintendent of Works, Royal Gardens, Kew, Surrey.

1894. Almond, Michael, District Locomotive Inspector, Cape Government Railways, Queenstown, South Africa: (or care of Robert Almond, 21 Hawthorn Road, South Gosforth, Newcastle-on-Tyne.)

1894. Ambler, Frank, Resident Engineer, Alagoas Railway, Maceio, Brazil.

1899. Ambrose, Sewell Powis, 35 Railway Road, Hollinwood, Manchester.

1900. Andrew, Samuel Ernest, Electric Lighting Works, Cathall Road, Leytonstone, London, E.

1898. Andrews, Frederic Ernest, Brush Electrical Engineering Co., Falcon Works, Loughborough.

1897. Appleby, Harry Walton, Messrs. Rosling and Appleby, Trafalgar Works, Bradford. [*Magneto, Bradford.* 844.]

1895. Armstrong, George Edwin, Municipal School of Science and Technology, Richmond Terrace, Brighton.

1899. Arnold, Arnold Attwood, Messrs. Ransomes, Sims and Jefferies, Orwell Works, Ipswich.

1898. Arnold, Frank William, Royal College of Science, Exhibition Road, South Kensington, London, S.W.; and 42 Summerfield Crescent, Birmingham.

1897. Arnold, William, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham.

1889. Ashford, John, Engineering Department, Northampton Institute, Clerkenwell, London, E.C.

1896. Atkinson, Frederic, Albert Buildings, 49 Queen Victoria Street, London, E.C. [*Fixed, London.*]

1898. Atkinson, Henry, 97 Queen Victoria Street, London, E.C.

1897. Atkinson, Robert Ernest, Messrs. Ashwell and Nesbit, Victoria Foundry, Sycamore Lane, Leicester. [*Plenum, Leicester.* 190.]

1897. Aylesbury, Thomas Antram, Durand House, 149A Clapham Road, London, S.W.

1899. Baber, Samuel Ernest, Superintendent Engineer, Menantic and Mendota Steamship Co., 52 Queen Square, Bristol.

1897. Back, Arthur Charles Lemprière, Devon and Cornwall Ice and Cold Storage Co., Plymouth.

1899. Backhouse, John, Messrs. Thomas Robinson and Son, Railway Works, Rochdale.

1899. Baker, Henry Gouldthorpe, Messrs. John Baker and Co., Brinsworth Works, Rotherham. [*Brinsworth, Rotherham.* 89.]

1897. Baker, John, Manager, Messrs. Tansley's Ice Works, Lower Fazeley Street, Birmingham.

1897. Baker, Tom William, 6 and 7 Broad Street House, London, E.C.

1899. Ball, Edmund Bruce, Messrs. Reavell and Co., Ranelagh Works, Ipswich.

1897. Ball, John, Geological Survey Office, Public Works Department, Cairo, Egypt.

1897. Bamber, Herbert William, Middlefield, Gainsborough.

1896. Barba, Alfonso G., Messrs. J. and G. Thomson, Clydebank, Glasgow; and Marie Place, 35 Crow Road, Partick, Glasgow.

1898. Barber, Thomas Walter, 17 and 18 Tothill Street, Westminster, S.W.

1896. Barker, Arthur Henry, Norwood Villa, Pontefract.

1893. Barker, Frederic William, 33A Broadway, Hammersmith, London, W. [*Barker, Broadway, Hammersmith.*]

1899. Barker, Thomas Perronet, Messrs. Thomas Piggott and Co., Atlas Works, Birmingham.

1894. Baron, Francis Edward, 62 Market Street, Manchester. [*Horseless, Manchester.* 4218.]

1896. Baron, James Thomas, Resident Engineer, St. Pancras Electricity and Public Lighting Department, 47 Stanhope Street, London, N.W.

1898. Bartle, George William, Albion Brewery, Mile End, London, E.

1896. Barton, Andrew, Admiralty, 21 Craven Street, Strand, London, W.C.

1900. Barty, Alexander Douglas, Manager, Messrs. Johnson and Phillips Victoria Works, Old Charlton, Kent.

1899. Bateman, Arthur Henry, Westcombe Hill Works, Greenwich, London, S.E. [*Petrifaction, London.*]

1897. Beck, John, European Petroleum Co., Balachany, near Baku, Russia; (or care of S. W. Kendall, Montrose, Avenue Road, Weymouth.)

1897. Beckton, William Rushworth, 13 Brownlow Street, Holborn, London, W.C.

1897. Bedbrook, James Albert Harvey, care of Messrs. R. and W. Hawthorn, Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1900. Begbie, Sydney Dawson, Managing Director, Begbie Manufacturing Co., 16 Holborn Viaduct, London, E.C.

1899. Begbie, William, Messrs. Thomas Begbie and Co., P.O. Box 459, Johannesburg, Transvaal, South Africa.

1898. Bell, William, Messrs. J. and E. Hall, Dartford.

1890. Bell, William Thomas, Mulgrave, St. Catherine's, Lincoln.

1896. Bentley, Wallace, Royal Insurance Buildings, Crossley Street, Halifax.

1898. Berry, Thomas, 53 Cowgate, Dundee. [*Steampump, Dundee.*]

1899. Beven, Alfred Nugent, Locomotive Superintendent, Junin Railway Co., Junin, Chile.

1899. Beves, Norman Ellison, Manager, Messrs. P. C. Middleton and Co., 10 North St. Andrew Street, Edinburgh. [*Resistance, Edinburgh.* 1205.]

1898. Bigger, Courtenay, Falmore Hall, Dundalk, Ireland.

1893. Bishop, Henry, 38 Gresham Street, Lincoln.

1897. Blakiston, Ralph, Superintending Engineer, Palatine Engineering Co., 10 Blackstock Street, Liverpool; and Waterloo, Liverpool.

1899. Blissett, Percival Thomas, Electric Power Transmission and Traction Co., Water Lane Works, Bradford.

1896. Blumfield, Thomas William, 157 Victoria Road, Aston, Birmingham.

1896. Bosley, Walter Joseph, Wharf Superintendent, Corporation Wharf, Southampton.

1895. Boulden, Frederick, Technical Department, University College, St. George's Square, Sheffield.

1898. Bouts, Thomas, Messrs. John Dewrance and Co., 158 Great Dover Street, London, S.E.; and 16 Althorpe Road, Tooting, London, S.W.

1898. Bradley, Godfrey Thomas, Town Hall, Southport.

1896. Bremner-Davis, William Joseph, The Brae, Alexandra Road, Malvern.

1898. Brett, Alfred William, Brett's Engineering and Stamping Works, Harnall Lane, Coventry. [*Bretts, Coventry.* 168.]

1898. Briggs, Herbert, P.O. Box 2318, Johannesburg, Transvaal, South Africa.

1898. Brindley, Harry Samuel Bickerton, 3 Awoicho Akasaka, Tokyo, Japan.

1895. Bruce, Robert Arthur, Brennan Torpedo Factory, Chatham.

1898. Bulfin, Ignatius, Municipal Offices, Bournemouth.

1892. Bulwer, Ernest Henry Earle, Linde British Refrigeration Co., 35 Queen Victoria Street, London, E.C.

1893. Burden, Alfred George, Messrs. Tangyes, P. O. Box 818, Johannesburg, Transvaal, South Africa: (or care of George N. Burden, Oakfield, Teignmouth.)

1895. Burn, George Francis, The Technical School, Cookridge Street, Leeds.

1890. Burne, Edward Lancaster, Messrs. Dickinson and Burne, Church Acre Iron Works, Guildford. [*Ploughshare, Guildford.* 40.]

1897. Burnside, Bertram W., Horsell, Woking.

1899. Burt, Thomas Ross, Mort's Dock and Engineering Co., Mort's Bay, Sydney, New South Wales.

1896. Butcher, Malcolm Henry, Messrs. F. A. Robinson and Co., 54 Old Broad Street, London, E.C.

1891. Butcher, Walter Edward, Messrs. S. Z. de Ferranti, Hollinwood, Manchester.

1891. Buttenshaw, George Eskholme, Stoneleigh, Rotherham.

1900. Calderwood, William, Works Manager, Messrs. Palmer and Co., Stratford, London, E.

1898. Cameron, Robert Barr, Municipal School of Science and Technology, Richmond Terrace, Brighton.

1899. Cannell, William, Manager, Auto-Machinery Co., Read Street, Coventry. [*Auto, Coventry.* 153.]

1896. Carolin, Edward Marlay, P. O. Box 80, Bloemfontein, Orange Free State, South Africa.

1898. Carr, James John William, Woodland Works, Grove Lane, Smethwick, Birmingham. [*Bells, Smethwick.* 2018.]

1899. Carrack, John William, Works Manager, Hosiery Machine Building Co., Bell Street Works, Nottingham.

1900. Carter, Samuel Arthur, Exeter Railway, 19 Bedford Circus, Exeter.

1899. Cater, John McIlvaine, Westinghouse Electric Co., 32 Victoria Street, Westminster, S.W.; and Southdown, The Downs, Wimbledon.

1897. Cerrito, Frank Henry, 71 Temple Row, Birmingham. [*Cerrito, Birmingham.*]

1895. Challenger, Godfrey Richard, Messrs. John Jameson and Son, Bow Street Distillery, Dublin.

1899. Chapman, Samuel, Mitchell's Emery Wheel Co., Mill Street, Bradford, Manchester.

1899. Cheffins, Harold William Joshua, Messrs. J. B. White and Brothers, Swanscombe, Kent.

1896. Clare, Ernest, care of Sidney Straker, 110 Cannon Street, London, E.C.

1899. Clark, George, Messrs. Bryan Donkin and Co., 55 Southwark Park Road, Bermondsey, London, S.E.; and Elm Tree Villa, Spittle, Chesterfield.

1894. Clark, James Lester, Messrs. Clark and Aiton, 102 Fenchurch Street, London, E.C. [*Channeled, London.*]

1899. Clarke, Arthur Laver, Gas Engineer, Gas Works, Maldon, Essex.

1895. Clatworthy, Walter Angove, 29 Lily Avenue, Jesmond, Newcastle-on-Tyne.

1898. Cleave, Arthur Harold Wyld, Royal Mint, London, E.

1897. Clegg, John Henry, Lower Lumb Mill, Heptonstall, Manchester.

1899. Clerk, Archibald, Messrs. Marks and Clerk, 25 Cross Street, Manchester. [*Anticipate, Manchester.* 4272.]

1900. Cluff, Richard, Southgate Engineering Co., New Southgate, London, N.; and 1 Grove Road, New Southgate, London, N.

1898. Cobbold, Arthur Westhorp, Plasafon, Pontrefelin, Portmadoc.

1899. Collins, William Lorenzo, 53 Berners Street, London, W.

1896. Comerford, Edward, Laragh, Victoria Park, Wavertree, Liverpool.

1897. Connell, William Percival, Calle Sanz 14, Minas de Rio Tinto, Huelva, Spain: (or care of W. G. Connell, 83 Cheapside, London, E.C.)

1896. Conradi, Julius Samuel, Messrs. John I. Thornycroft and Co., Church Wharf, Chiswick, London, W.

1900. Coombs, James Alger, Messrs. Hughes and Lancaster, Acrefair, Ruabon.

1899. Cooper, George, Leeds Forge, Leeds.

1896. Cooper, Thomas, Cox Thermo Electric Co., St. Albans; and Spring Valley, Beaconsfield Road, St. Albans.

1900. Cooper, William James, 83 and 84 Bromsgrove Street, Birmingham. [*Thermal, Birmingham.*]

1895. Corby, Matthew, Messrs. Thomas Firth and Sons, Norfolk Works, Sheffield; and 160 Hagley Road, Birmingham.

1899. Corrie, John Bradford, Palace Chambers, 9 Bridge Street, Westminster, S.W.

1894. Coventry, Theodore, Messrs. Smith and Coventry, Gresley Iron Works, Ordsal Lane, Salford, Manchester. [*Gresley, Manchester.* 564.]

1895. Cowie, William, 48 Church Street, Coatbridge.

1896. Cox, Edward Henry, De la Vergne Refrigerating Machine Co., Foot of East 138th Street, New York, United States.

1897. Craig, Alexander, Messrs. Humber and Co., Coventry.

1897. Crooke, Walter, Jun., Frodingham, near Doncaster.

1887. Crosland, Delevante William, 1 Upper Addison Gardens, Kensington, London, W.

1899. Cunliffe, Tom Arthur, British Electric Traction Co., Donington House, Norfolk Street, Strand, London, W.C.

1895. Cust, Leopold, Gas Traction Co., 22 Chancery Lane, London, E.C.; and 99 Onslow Square, London, S.W.

1894. Dadina, Hormuz Minocher, Messrs. St. Paul and Dadina, Graham's Buildings, Bombay, India.

1894. Davey, Edward Ernest George, Polytechnic School of Engineering, 309 Regent Street, London, W.

1896. Davidson, John McKenzie, General Contractor, Karachi, India.

1898. Davies, Hugh, 37 Bryantwood Road, Highbury, London, N.

1896. Davis, Francis Myddleton, Works Manager, Messrs. R. and T. Elworthy, Elizabethgrad, Russia.

1897. Davy, David, Jun., Messrs. Davy Brothers, Park Iron Works, Sheffield. [*Motor, Sheffield.*]

1890. Day, Arthur Godfrey, Director of Studies, Science Art and Technical Schools, Guildhall, Bath.

1899. Day, Claud Albert Stainton, Electrical Engineer's Office, (Waterloo and City Railway), London and South Western Railway, Launcelot Street, London, S.E.

1899. De Ville, Martin, Vulcan Boiler and General Insurance Co., Manchester.

1898. Dickinson, William, Messrs. Dickinson and Burne, Church Acre Iron Works, Guildford. [*Ploughshare, Guildford.* 40.]

1898. Dobbs, Herbert Treadwin, Locomotive Carriage and Wagon Department, Barry Railway, Barry, near Cardiff.

1899. Dodridge, Frederick, Chief Engineer's Department, Keyham Dockyard, Devonport; and 6 Ilbert Street, Plymouth.

1898. Donald, David Boswell, Manager, Messrs. John Freeman, Sons and Co., Penryn. [*Freeman, Penryn.*]

1898. Donne, Frederick Edward Mowbray, Locomotive Department, Midland Railway, Derby.

1896. Dossor, Herbert, Babcock and Wilcox Co., 147 Queen Victoria Street, London, E.C.

1898. Douglas, William James, 141 Fenchurch Street, London, E.C. [*Blockading, London.*]

1899. Douglas, William Saunders, Consett Iron Works, Consett, R.S.O., County Durham; and 60 Durham Road, Blackhill, R.S.O., County Durham.

1891. Douglass, Alfred Edwards, South Staffordshire Water Works, Paradise Street, Birmingham.

1896. Dowson, Erasmus Charles Head, Lattendales, Penrith.

1898. Dowson, Robert Manning, Felixstowe, The Park, Nottingham.

1895. Dronsfield, James, Messrs. Dronsfield Brothers, Atlas Works, Oldham.

1895. Dumas, Robert, Messrs. Siemens Brothers and Co., Woolwich.

1895. Duncan, William, Locomotive Department, Cape Government Railways, Uitenhage, Cape Colony.

1894. Dunolly, Alan, H.M. Inspector of Factories, 19 Market Street, Huddersfield.

1894. Eastmead, Frederic James, Messrs. Moffatt and Eastmead, 39 Victoria Street, Westminster, S.W. [*Hoistway, London.*]

1893. Edmondson, Alfred Richard, The Oaks, Moss Lane, Timperley, Altrincham.

1898. Edwards, Edgar Llewellyn, 119 Colmore Row, Birmingham.

1899. Edwards, James George Benjamin, Southern Higher Grade School, Bewerley Street, Leeds.

1900. Ellington, Guy, London Hydraulic Power Co., 9 Bridge Street, Westminster, S.W.

1898. Ellis, Jesse, Invicta Works, St. Peter Street, Maidstone. [*Jesse Ellis, Maidstone.* 2.]

1898. Enock, Donald, P. O. Box 121, care of Reuter, Durban, Natal.

1899. Enock, Eric Cuthbert, Manager, Messrs. W. Ball and Co., Coombe Engine Works, Dartmouth.

1897. Epton, William Martin, North Carlton, Lincoln.

1900. Evans, Griffith Cooper, Messrs. Taite, Howard and Co., 63 Queen Victoria Street, London, E.C.

1899. Everson, Frederick Charles, Messrs. Bramwell and Harris, 5 Great George Street, Westminster, S.W.

1899. Fairley, Frank, 9 Queen Street Place, London, E.C.

1895. Fawcett, Percy William, Whirlow Court, Sheffield.

1894. Fendick, Walter, Gas Works, Hemel Hempstead.

1896. Fforde, William John, 2 Glenview Terrace, Springfield Road, Belfast.

1894. Finlayson, David, Burnhead, Larbert, Stirlingshire.

1896. Firth, John, 25 Jowett Street, South Reddish, Stockport.

1894. Fitz-Gerald, John Frederick Gerald, care of El Señor Ingeniero, Departamento de Vias y Obras F.C.S., Buenos Aires, Argentine Republic.

1895. Fleischer, Paul, Messrs. A. Guinness, Son and Co., St. James' Gate Brewery, Dublin.

1898. Fletcher, Harold Clarkson, Messrs. Johnson and Fletcher, P.O. Box 580, Bulawayo, Rhodesia, South Africa.

1892. Fletcher, Joseph Ernst, Messrs. Charles Cammell and Co., Cyclops Works, Sheffield.

1899. Flint, Leonard Robert, Babcock and Wilcox Co., 147 Queen Victoria Street, London, E.C.

1895. Forbes, George Chichester, Locomotive Department, South Indian Railway, Negapatam, India.

1895. Foster, Edward Hornby, Messrs. John Foster and Son, Black Dike Spinning Mills, Queensbury, near Bradford.

1898. Fowler, Percy Merwood, 43 Threadneedle Street, London, E.C.

1899. Fox, Frederick Joseph, Messrs. Bryan Corcoran, Back Church Lane, Whitechapel, London, E.; and 49 Farquhar Road, Upper Norwood, London, S.E.

1899. Fox, Henry Shoolbred, Manager, Messrs. G. J. Worssam and Son, Wenlock Road, City Road, London, N. [*Massrow, London.* King's Cross 677.]

1896. Fraser, Frank Hazell, Messrs. W. J. Fraser and Co., 98 Commercial Road East, London, E. [*Fraser, Engineer, London.* Avenue 4413.]

1899. Freeman, Walter William, Villette, Belgrave Road, Longton, Staffordshire.

1899. French, Arthur Houle, London Electric Supply Corporation, Stowage Wharf, Deptford, London, S.E.

1897. Frerichs, Jacob Andrew, Construction Department, East Rand Proprietary Mines, Boksburg, Transvaal, South Africa.

1899. Fulcher, George Chambers, Engineer-in-Chief's Office, G.P.O. West, St. Martin's-le-Grand, London, E.C.; and 88 Brooke Road, Stoke Newington, London, N.

1897. Furness, Charles, Borough Electrical Engineer, Technical Schools, Devonport.

1900. Furnivall, William Henry Graham, care of H. B. Marshall, P.O. Box 127, Cape Town, Cape Colony.

1899. Gale, Robert Harry, 38 Scarsdale Villas, Kensington, London, W.

1896. Gallé, William Alexandre, Locomotive Department, Great Central Railway, Gorton, Manchester.

1899. Garbutt, Henry, Messrs. Kynoch, Birmingham.

1896. Garratt, James Herbert, Messrs. Whittall and Co., Colombo, Ceylon.

1896. Garrett, Easton, Messrs. Bailey, Walker and Co., 456 Calle Cuyo, Buenos Aires, Argentine Republic.

1890. Garrett, Frank, Jun., Messrs. Richard Garrett and Sons, Leiston Works, Leiston, R.S.O., Suffolk.

1898. Garvey, Richard Godfrey Hamilton, Messrs. Bowes, Scott and Western, Bridge Road, Battersea, London, S.W.

1898. Gass, John, Engineer's Office, The Tower Bridge, 9 Horselydown Lane, London, S.E.

1900. Gaston, Alfred Benjamin, care of Archibald Little. Shanghai, China.

1900. George, James MacNaughten, Messrs. Richards, Broadford Works, Aberdeen.

1899. Gibbins, John Ernest, Messrs. Moorwood. Sons and Co., Harleston Iron Works, Sheffield.

1900. Gibson, George Henry, care of D. Home Morton, 95 Bath Street, Glasgow.

1900. Ginders, Ernest Marsh, Managing Director, Cleveland Works, Cleveland Street, Birkenhead. [*Construct, Birkenhead.* 280.]

1899. Girvan, William, Sandakan Engineering Works, Sandakan, British North Borneo.

1896. Given, Ernest Cranston, Messrs. Priestman and Co., Philadelphia, Pennsylvania, United States; and The Lodge, Aigburth, Liverpool.

1896. Goffe, Edward, De Beer's Consolidated Mines, Kimberley, South Africa.

1898. Golding, Henry Albert, Messrs. Bryan Donkin and Co., 55 Southwark Park Road, Bermondsey, London, S.E.

1900. Goodman, Alfred Christian, Manager, Messrs. J. and W. Marshall and Co., Monway Iron Works, Grove Street, Smethwick, near Birmingham.

1898. Gordon, James, Messrs. Ralph Douse and Sons, 23 Billiter Buildings. London, E.C. [*Exportamus, London.* Avenue 5857]; and 23 St. James' Mansions, West End Lane, West Hampstead, London, N.W.

1897. Gordon, John Wilton, Messrs. John Gordon and Co., Dashwood House, 9 New Broad Street, London, E.C.

1899. Goulstone, Ernest Edwin, Superintendent, Water and Sewage Works. Cawnpore, India.

1898. Graham, Hubert Berger, Linden House, Gough Road, Edgbaston, Birmingham.

1897. Grant, Hector, 183 West George Street, Glasgow.

1896. Grant, William, Messrs. Workman, Clark and Co., Engine Works, Queen's Road, Belfast.

1896. Gray, Alexander Cuthill, Assistant Locomotive Superintendent, Rio Grande do Sol Railway, Rio Grande do Sol, Brazil.

1899. Green, John Singleton, Municipal Offices, Haslingden, near Manchester.

1900. Greene, Frank Arnold, Messrs. Henry Greene and Co., 22 Martin's Lane, London, E.C. [*Three Keys, London.* Bank 5827.]

1900. Griffiths, William John, Messrs. McKenzie and Holland, 61 Sinclair Road. West Kensington, London, W.

1900. Grimley, William Richard Nash, Chief Engineer, Alliance Electrical Co., 137 Regent Street, London, W.

1893. Gritton, Joseph, 8 Lumley Road, Chester.

1895. Groundwater, Samuel, Messrs. S. C. Farnham and Co., Old Dock, Shanghai, China.

1897. Grove, Harry, Messrs. Willey and Co., Exeter.

1895. Groves, Montague, Moore's Rhodesia Concession, Salisbury, Mashonaland, South Africa.

1894. Hadengue, Charles Benjamin, Messrs. Carew and Co., Rosa Sugar Works, Rosa, North Western Provinces, India.

1899. Hadley, William Pearce Holbrow, Dhendi Tea Estate, Borjuli P.O., Tezpore, Assam, India.

1895. Haines, Charles James, Southampton Water Works, Otterbourne, near Winchester.

1896. Hall, Benjamin James, 39 Victoria Street, Westminster, S.W.

1894. Hall, Robert Frederick, Ferndale, Church Road, Moseley, Birmingham.

1897. Halsey, Charles Turner, Messrs. J. and E. Hall, Dartford; and 1 Shepherd's Lane, Dartford.

1894. Hardy, William, Woodview, Bessbrook, County Armagh, Ireland.

1898. Harling, William, British Electric Traction Co., Donington House, Norfolk Street, Strand, London, W.C.

1897. Harlow, Bernhard Schäffer, Messrs. Robert Harlow and Son, Heaton Norris Brass Works, Stockport.

1894. Harris, Herbert Nelson, St. Michael's Foundry, Bridport.

1899. Harwood, James Henry, Messrs. Maudslay, Sons and Field, Lambeth, London, S.E.

1897. Harwood, Robert Henry, Howrah Jute Mills, Seebpore, Calcutta, India.

1900. Haughton, George Bayly, Messrs. Haughton and Co., 6 Lombard Court, London, E.C. [*Haughnot, London.*]

1896. Hawes, David Marc Andrew Graham, 19 and 21 Queen Victoria Street, London, E.C.

1897. Hawes, William Fox, Jun., Messrs. Kincaid, Waller and Manville, 29 Great George Street, Westminster, S.W.

1897. Hawkins, Thomas Spear, St. John del Rey Mining Co., Morro Velho, Brazil.

1900. Hawksworth, Frederick Sydney, Messrs. John Spencer and Co., Globe Tube Works, Wednesbury.

1896. Heath, Charles Lewis Eclair, Municipal Technical School, 86 Osborne Street, Hull.

1897. Hemingway, Alfred, Great Southern Railway, Albany, Western Australia.

1894. Henderson, Arthur James, 60 Queen Victoria Street, London, E.C. [*Enginery, London.*]

1899. Hepworth-Collins, Walter, care of 26 Coupland Street, Oxford Road, Manchester.

1898. Herschmann, Arthur Julius, care of Adams Co., 59 Broadway, New York, United States.

1899. Hildage, Henry Thomas, Engineer's Office, Great Central Railway, Manchester.

1898. Hill, Alfred Percy, Messrs. J. and P. Hill, Backfields and Norfolk Iron Works, Sheffield. [*Hill, Backfields, Sheffield.*]

1898. Hill, Joseph, Messrs. Clark and Aiton, 25 Laurence Pountney Lane, London, E.C.

1897. Hill, Walter Charles, 48 Heathwood Gardens, Little Heath, Charlton, Kent.

1898. Hirst, George Frederick, Rotherham Main Colliery, Rotherham.

1899. Hitchins, Charles Faunce, Messrs. Walter Basset and Co., 110 Westminster Bridge Road, London, S.E.; and Junior Constitutional Club, Piccadilly, London, W.

1895. Hockley, Norman Julius, care of P. F. Scanlan, Armitage Chambers, Victoria Street, Nottingham.

1898. Hodgson, Richard Broom, Woodside, Westfield Road, King's Heath, Birmingham.

1899. Hollingsworth, Allen Alexander, Messrs. Henry Bessemer and Co., Carlisle Street East, Sheffield.

1896. Hollingsworth, Edward Massey, St. Helens Corporation Electricity Works, St. Helens, Lancashire.

1899. Holmes, Harry, City Engineer's Office, Birmingham.

1898. Holroyd, Victor Avison, Works Manager, Messrs. Rudge-Whitworth, Coventry.

1898. Honiball, Charles Roland, Liverpool Engineering and Condenser Co., Perry Street Engine Works, Brunswick Dock, Liverpool.

1895. Horner, Joseph Gregory, 17 Vernon Terrace, Twerton-on-Avon, Bath.

1899. Horsnaill, William Owen, Messrs. Crompton and Co., Arc Works, Chelmsford.

1900. Howell, Edwin James, Alliance Electrical Co., 137 Regent Street, London, W.

1899. Hughes, Francis Edward Harold, care of G. T. Harrap, 5 Budge Row, Cannon Street, London, E.C.

1898. Hughes, George Henry, Kent Water Works, Deptford, London, S.E.; and 7 Lawn Villas, Wisteria Road, Lewisham, London, S.E.

1899. Humphreys, William Henry, Manager, York Water Works, Lendal Hill, York. [42.]

1899. Hunt, Henry, Messrs. G. J. Worssam and Son, Wenlock Road, City Road, London, N.; and Cotsford, Uplands Park, Enfield.

1894. Hyde, George Herbert (*Life Associate Member*), Managing Engineer, Colombo Commercial Co., Colombo, Ceylon.

1896. Iden, George, Motor Mills, Coventry.

1898. Inglis, William Rowland Hugh, Redbourn Hill Iron and Coal Co., Frodingham, near Doncaster.

1897. Ironside, William Allan, Messrs. Ironside, Son and Co., 1 Gresham Buildings, Guildhall, London, E.C. [*Ironside, London.*]

1897. Irvine, Archibald John, P.O. Box 149, Johannesburg, Transvaal, South Africa.

1896. Issigonis, George Demos, The D. Issigonis Works, Smyrna, Turkey in Asia.

1899. Jackling, Daniel C., De La Mar's Mines, Mercur, Utah, United States.

1898. Jackson, Ernest, Westfield, Cornwall Road, South Tottenham, London, N.

1900. Jackson, Harold Drinkwater, Manager, Messrs. Barr and Stroud, 250 Byres Road, Glasgow.

1898. Jackson, Harry Loxton, Messrs. Jackson and Brother, Wharf Foundry, Bolton. [*Jackson, Bolton.* 34.]

1898. Jackson, Robert Hiram, Messrs. Schäffer and Budenberg, Whitworth Street, London Road, Manchester; and 90 Elizabeth Street, Cheetham, Manchester.

1898. James, Henry Haughton Rhodes, 13 Victoria Street, Westminster, S.W.

1898. James, William Henry, University College of South Wales and Monmouthshire, Cardiff.

1893. Jenkin, Charles James, Council Offices, Willenhall, Wolverhampton.

1897. Johns, Cosmo, Messrs. Vickers, Sons and Maxim, River Don Works, Sheffield.

1896. Johnson, Andrew, 120 Nithsdale Road, Glasgow.

1897. Johnson, George, Messrs. Johnson and Fletcher, P.O. Box 580, Bulawayo, Rhodesia, South Africa.

1898. Johnson, Walter Wroe, Castleton Foundry and Engineering Works, Armley Road, Leeds.

1890. Jones, Arthur Dansey, Locomotive Department, Lancashire and Yorkshire Railway, Horwich, near Bolton.

1896. Jones, Thomas Gilbert, The Technical School, Mount Pleasant, Swansea.

1889. Joy, Basil Humbert, 85 Gracechurch Street, London, E.C.; and 118 Broadhurst Gardens, West Hampstead, London, N.W.

1899. Joyce, Thomas Walter, Council Offices, Llandudno.

1899. Kempt, Alfred Rodney, R.N., H.M.S. "Renown," Mediterranean Fleet.

1895. Kennedy, Robert Baird, Belle Vue House, Linthorpe, Middlesbrough.

1899. Kensington, John Charlton, Resident Engineer, San Salvador Railway and Works, Astillero, Provincia de Santander, Spain.

1896. Kerr, Alfred Ernest Campbell (*Life Associate Member*), The School of Mines, Ballarat, Victoria.

1898. Kerr, James B., Clarkson and Capel Steam Car Syndicate, Deverell Street, Great Dover Street, London, S.E.

1899. Kershaw, Grindrod, Rochdale Municipal Technical School, Nelson Street, Rochdale.

1894. Kerslake, Walter Edmund, 16 Woodland Road, Walton, Liverpool.

1897. Ketley, Charles Bosworth, 128 Colmore Row, Birmingham. [*Invent, Birmingham.* 1132.]

1897. King, Andrew, 361 Lenton Boulevard, Nottingham.

1893. Kirk, Percy Roebuck, Hackney Technical Institute, Cassland Road, London, N.E.

1896. Kitto, William Henry, Morvah, Hartington Road, Grove Park, London, W.

1897. Lacy-Hulbert, Charles Edward, 45 Rue Henri Maus, Brussels, Belgium. [*Hulbert, Bruxelles.* 3723.]

1895. Larard, Charles Edward, The Technical College, Huddersfield.

1897. Larmuth, John Hamilton, Messrs. Thomas Larmuth and Co., Todleben Iron Works, Unwin Street, Cross Lane, Salford, Manchester; and 452 Eccles New Road, Weaste, near Manchester.

1898. Larmuth, William Oliver, Messrs. Thomas Larmuth and Co., Todleben Iron Works, Unwin Street, Cross Lane, Salford, Manchester; and 103 York Terrace, Eccles Old Road, Pendleton, Manchester.

1899. Lash, Horatio William, Manager, Albion Works, Sheffield.

1896. Lawson, Harry John, 40 Holborn Viaduct, London, E.C.

1893. Lea, Arthur Henry, Messrs. Lea and Warren, Kettering.

1897. Leitch, Archibald, 40 St. Enoch Square, Glasgow. [*Tracing, Glasgow.* Royal 5197.]

1898. Leonard, Peter, 75 Victoria Road, Great Crosby, Liverpool.

1895. Longbottom, John Gordon, Glasgow and West of Scotland Technical College, 38 Bath Street, Glasgow.

1900. Longley, Henry Banks, Engineer, Moss Side Urban District Council, Moss Side, Manchester.

1898. Love, Robert Templeton, Royal Bank House, Stewarton, R.S.O., Ayrshire.

1896. Lovell, Samuel George, 73 The Crescent, South Tottenham, London, N.

1898. Lund, John, Messrs. Ashwell and Nesbit, 12 Great James Street, Bedford Row, London, W.C.

1897. MacIvor, Alexander, Messrs. Potter and Co., Hollins Paper Mills, Darwen.

1898. Macnab, James, Messrs. Pollock and Macnab, Britannia Iron Works, Hyde, near Manchester. [*Macnab, Hyde.* 227.]

1896. Mansfield, Alfred, Messrs. Mansfield and Sons, 9 Second Line Beach, Madras, India. [*Gaslight, Madras.*]

1899. Mansfield, James Francis, Electric Traction Co., 16 Great George Street, Westminster, S.W.

1897. Mansfield, Walter, Messrs. Mansfield and Sons, 9 Second Line Beach, Madras, India. [*Gaslight, Madras.*]

1899. Marshall, Launcelot Paul, City Engineer's Office, Guildhall, Norwich.

1896. Martin, George Best, Works Manager, British Tube Co., Cornwall Road, Smethwick, Birmingham.

1899. Martin, John, Charing Cross and Strand Electric Supply Corporation, 85 Commercial Road, Lambeth, London, S.E.

1900. Massey, Edward, Dallam Forge, Warrington.

1895. Massey, Leonard Fletcher, Messrs. B. and S. Massey, Openshaw, Manchester. [*Masseys, Openshaw.* 300.]

1899. Maw, Henry, 17 Victoria Street, Westminster, S.W.

1899. McAll, Henry Wardlaw, 2 Spring Gardens, Teignmouth.

1899. McBean, John, East Rand Proprietary Mines, Boksburg, Transvaal, South Africa.

1899. McCormack, Arthur John, Griffiths Cycle Corporation, 33 Earl Street, Coventry.

1896. McCormack, William John, 19 Kensington Court, London, W.

1899. McFerran, Howard A., Chief Engineer, Royal Courts of Justice, Strand, London, W.C.; and 44 Effingham Road, Lee, London, S.E.

1894. McGeorge, James, Bombay Burmah Trading Corporation, Rangoon, British Burmah, India.

1898. McGregor, John, Messrs. Murray and Paterson, Coatbank Engine Works, Coatbridge.

1900. McLaren, John Alexander, Westbrook, Barrington Road, Crouch End, London, N.

1891. McMeekin, Adam, Cogry Flax Spinning Mills, Doagh R.S.O., Co. Antrim, Ireland.

1899. McTaggart, John, Superintendent and Engineer, Ashpit Cleansing and Destructors' Department, Hammerton Street, Bradford.

1900. Meek, George Thomas, Hammersmith Electricity Works, Fulham Palace Road, Hammersmith, London, W.

1898. Meek, John, Managing Director, Coventry Eagle Cycle Co., Lincoln Street, Coventry. [*Eagle, Coventry.* 129.]

1897. Meggitt, George Teale, Messrs. Samuel Meggitt and Sons, Hamilton Road, Sutton-in-Ashfield, Nottingham.

1895. Messer, Edgar Harrisson, Consolidated Goldfields of South Africa, 8 Old Jewry, London, E.C.

1899. Middleton, Harry Herbert, 30 Dalhousie Square South, Calcutta, India.

1894. Mills, Arthur Edwin, Ivy Villa, Downend, Bristol.

1899. Mills, Joseph Amos, Salisbury Gold Mining Co., P.O. Box 1017, Johannesburg, Transvaal, South Africa.

1897. Mills, Samuel James Augustus, Belgrave Mills, Darwen.

1898. Mindo, Arnold Waldemar, 52 Serpentine Road, Egremont, Cheshire.

1893. Mitchell, James Frederick Bruce, Messrs. J. F. B. Mitchell and Co., Mazagon Iron Works, Bombay, India.

1896. Mitton, Thomas Evans, Messrs. Hunt and Mitton, Crown Brass Works, Oozells Street North, Birmingham. [*Mitton, Birmingham.* 394.]

1894. Monckton, Charles John, Phoolultah Tea Estate, Sagurnal Post Office, Sylhet, Assam, India.

1896. Moncrieff, Robert Wighton, The Grange, Stoke Goldington, Newport Pagnel.

1895. Moore, Thomas Lamb, Messrs. James Moore and Sons, Millfield Foundry, Belfast. [*Moore, Millfield, Belfast.* 466.]

1898. Morris, William Joseph, Sheepbridge Iron Works, Chesterfield.

1897. Moule, Frederick Oswald, Messrs. Ruston, Proctor and Co., Sheaf Iron Works, Lincoln.

1893. Mountain, Benjamin, South Parade, Leeds.

1895. Mount-Haes, Andrew, Humboldt Engineering Works, Kalk, near Cologne, Germany.

1893. Moylan, William Morgan, care of Messrs. Grindlay and Co., Calcutta, India.

1899. Muirhead, David, Kirkintilloch, Glasgow.

1899. Munn, John Adam, Manager, Messrs. K. L. Mukerjee and Co., 19 Sukea's Lane, Calcutta, India.

1898. Munyard, Alfred, Messrs. Maudslay, Sons and Field, Lambeth, London, S.E.

1894. Murphy, Edward Owen, R.N.R., Messrs. Bailey and Murphy, 17 Praya Central, Hong Kong, China.

1897. Nakagawa, Goeokichi, Chief Engineer, Tokyo Gas Co., Tokyo, Japan.

1900. Naylor, Joe, Messrs. Elkanah Hoyle and Sons, Waterside Works, Halifax.

1899. Neal, Robert Henry Bennett, Bolitho Bank Chambers, Princess Square, Plymouth. [*Output, Plymouth.* 594.]

1899. Nettlefold, Godfrey, Messrs. Nettlefolds, Heath Street, Birmingham. [*Nettlefolds, Birmingham.* 2086.]

1896. New, Alfred Wilmot, Messrs. D. New and Co., 31 Devonshire Chambers, Bishopsgate Street Without, London, E.C.

1896. New, David James, Messrs. D. New and Co., 31 Devonshire Chambers, Bishopsgate Street Without, London, E.C.

1896. Newell, Ernest, Messrs. Ernest Newell and Co., Stockwith-on-Trent, Gainsborough. [*Woods, Misterton.*]

1897. Newman, Reginald William, Messrs. John Aird and Sons, Birmingham Corporation Water Works, Northfield, Birmingham.

1896. Nicholls, Percy, Oak Villa, Pontefract.

1894. North, Horace, St. George's Engineering Works, Trafalgar Street, Brighton.

1897. Norton, Arthur, Dunwich, Stanmore Road, Edgbaston, Birmingham.

1899. Norton, Samuel Joseph, Works Manager, Messrs. De Winton, Carnarvon; and 12 Gelert Street, Carnarvon.

1899. Oates, Arthur Job, 90 Franchise Street, Wednesbury.

1900. Ockenden, Maurice Albion, Jun., Messrs. Duke and Ockenden, Ferry Wharf, Littlehampton.

1898. Ogden, Cuthbert Charles, 112 St. Edmund's Terrace, Rochdale.

1898. Oldham, Harry George Vincent, Manager, Ratner Safe Works, Hancock Road, Bow, London, E.; and 357 Old Kent Road, London, S.E.

1899. Osburn, George Victor, Messrs. Topham, Jones and Railton, Gibraltar.

1899. Oswald, George Herbert, Engineer's Office, Great Western Railway, Newport, Mon.

1897. Page, Henry, 30 Heathcote Street, Nottingham.

1900. Palmer, Henry Boswell, Jun., Driefontein Consolidated Mines, Boksburg, Transvaal, South Africa: (or 13 Chapter Road, Willesden Green, London, N.W.)

1897. Parish, Charles Edward, Ouston Collieries, Chester-le-Street, Co. Durham.

1900. Parker, Henry Albert, Messrs. Simpson and Co., 101 Grosvenor Road, Pimlico, London, S.W.; and 15 South Place, Kennington Park, London, S.E.

1896. Parker, John, Messrs. E. Green and Son, 2 Exchange Street, Manchester.

1898. Parsons, Harry, Cold Harbour, Earlsdon, near Coventry.

1896. Patel, Motibhai Bhikhabhai, Bhadran, near Borsad, India.

1896. Patel, Raojibhai Motibhai, Principal, Kala-Bhavan, Baroda, India.

1893. Paterson, Robert Mair, 119 Hamilton House, Bishopsgate Street Without, London, E.C.

1900. Payne, Henry, University College, Gower Street, London, W.C.

1899. Pearce, Standen Leonard, British Thomson-Houston Co., 24 Bulwer Street, Shepherd's Bush, London, W.

1898. Pedley, Heber Isaac, Messrs. Rudge-Whitworth, Rea Street South, Birmingham.

1896. Pendred, Loughnan St. Lawrence, 33 Norfolk Street, Strand, London, W.C.

1895. Penn, William Cooper, 25 Victoria Street, Westminster, S.W. [*Penniform, London.* Westminster 75.]

1893. Pertwee, Herbert Arthur, Nelson Iron Works, Great Yarmouth.

1899. Petter, Percival Waddams, Works Manager, Messrs. James B. Petter and Sons, Nautilus Works, Yeovil. [*Petter, Yeovil.*]

1897. Phillips, Edwin Grant, care of Philip Jackson, San Agustin 3 dup., Madrid, Spain.

1899. Phillott, George Henry, 13 Promenade, Cheltenham.

1900. Pickering, Frank, Cape Government Railways, Cape Town, Cape Colony.

1897. Pickles, John Edward, Denholme, Broadway Road, Bishopston, Bristol.

1899. Pigott, Arthur, Babcock and Wilcox Co., 14 Deansgate, Manchester.

1898. Pillatt, Andrew, Queen's Road Works, Nottingham.

1899. Pilling, Frederick Stott, 10 Stoke Terrace, Devonport.

1891. Pirrie, John Barbour, Barn Flax Spinning Mills, Carrickfergus, Co. Antrim, Ireland.

1898. Platts, William, Messrs. George Turton, Platts and Co., Savile Street, Sheffield. [*Buffer, Sheffield.*]

1897. Player, Ralph, Messrs. Joseph Wright and Co., Neptune Works, Tipton.

1896. Pollard, Lieutenant Ferdinand Joseph, No. 5 Company, Railway Pioneer Regiment, 22 Atkinson Buildings, Cape Town, Cape Colony.

1898. Porritt, Louis Alfred, Messrs. William Tatham and Co., Vulcan Works, Rochdale.

1897. Porter, Stanley William, 32 Queen Victoria Street, London, E.C.

1895. Powell, Benjamin Newton, Manager, Lidgerwood Manufacturing Co., Soerabaya, Java: (or care of C. T. Powell, Cherry Street, Birmingham.)

1900. Powell, David Thomas, care of Dr. Alexander B. W. Kennedy, 17 Victoria Street, Westminster, S.W.

1899. Powell, Ernest Brecon, Messrs. Whitehead and Co., Portland Harbour Torpedo Works, Weymouth.

1899. Powrie, William Lyall, Messrs. Furnival and Co., 32 St. Bride Street, London, E.C.

1898. Prance, Cyril Rooke, The Priory, Mansfield Woodhouse, Mansfield.

1897. Price, Charles Graham, Cawdor Villa, Ross, Herefordshire.

1899. Price, William Frederick, Callender's Cable and Construction Co., Oldham Place, Renshaw Street, Liverpool.

1887. Price-Williams, John Morgan, Drakelow, Wolverley, Kidderminster.

1899. Prockter, Frederick Malcolm, Beaverstown House, Donabate, County Dublin.

1899. Pugh, John Vernon, 34 Spon Street, Coventry.

1895. Pullar, Albert Evans, Pullar's Dye Works, Perth.

1900. Purves, William Thompson, 47 York Place, Edinburgh. [1259.]

1899. Quilter, Frederic Russell, Palace Chambers, Westminster, S.W.

1899. Radley, Bertram Vernon, East India Railway, Asansol, India.

1894. Raleigh, Charles, 58 Chancery Lane, London, W.C.

1899. Rapson, Josiah Trevor, Helicoid Locknut Patents Co., Acton Hill Works, Acton, London, W.

1898. Ravenhill, William Arthur, Chief Mechanical Engineer, Royal Gun Carriage Factory, Madras, India.

1896. Rayner, Harry Stafford, Dowson Economic Gas and Power Co., 39 Old Queen Street, Westminster, S.W.

1899. Read, George Henry, National Cash Register Co., 337 Strand, London, W.C.

1899. Redding, Walter, 87 Oak Road, New Wortley, Leeds.

1892. Redfern, Charles George, 4 South Street, Finsbury, London, E.C. [*Invention, London.* Avenue 691.]

1899. Richardson, John Robert, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1893. Richey, William Frederick Albert, Messrs. Chance Brothers and Co., Lighthouse Works, near Birmingham.

1895. Ridley, Clarence Oliver, Sir W. G. Armstrong, Whitworth and Co., 8 Great George Street, Westminster, S.W.

1896. Rieter, E. Henry, Messrs. Rieter and Koller, Emishofen, near Constance, Switzerland.

1899. Roberts, Basil Owen, care of T. H. Douglas, The Bank, Coldstream.

1893. Roberts, Charles Thomas, Salisbury, Rhodesia, South Africa.

1899. Roberts, Percy Roper, P.O. Box 31, Salisbury, Rhodesia, South Africa.

1899. Rochat, Henri Louis, 3 and 4 Hare Street, Calcutta, India.

1898. Rodda, Joseph Tonkin, Water Works Superintendent, 14 Seaside Road, Eastbourne.

1897. Rogers, William Ivy, Managing Director, New Merlin Cycle Co., New Summer Street, Birmingham. [*Temptation, Birmingham.* 1817.]

1897. Rolf, George, Messrs. Ernest Scott and Mountain, Close Works, Newcastle-on-Tyne; and 8 Bentinck Crescent, Newcastle-on-Tyne.

1899. Rosevere, Gerald Rhodes, Britannia Railway Carriage and Wagon Works, Saltley, Birmingham.

1895. Ross, Ernest Sydney, Chief Inspector of Machinery, Public Offices, Hobart, Tasmania.

1894. Rossiter, James Thomas, Tynwald, Grove Park Road, Chiswick, London, W.

1884. Roux, Paul Louis, 54 Boulevard du Temple, Paris.

1899. Rowe, John, Block B, Langlaate Estate, P.O. Box 98, Johannesburg, Transvaal, South Africa.

1897. Roylance, Arthur Herbert, Haworth's Buildings, 5 Cross Street, Manchester.

1896. Ruffle, Frank Felingham, care of Messrs. Ralli Brothers, Calcutta, India.

1898. Russell, Bridgman, 42 Berwick Street, Oxford Street, London, W. [*Ventilabro, London.* Gerrard 5349.]

1895. Russell, Frederick, Manager, Gas Works, Bexhill-on-Sea.

1899. Russell, Hubert, Engineer, Gas Works, Holmfirth, Huddersfield.

1897. Ruthen, Charles Tamlin, Bank Chambers, Heathfield Street, Swansea.

1897. Rycroft, John Edward, Engineering Department, Technical College, Bradford.

1894. Salis, Henry Rodolph de, Ivy Lodge, Iver Heath, near Uxbridge.

1896. Samuel, Blelock Lee, Grahamston Foundry and Engine Works, Barrhead, near Glasgow.

1897. Sanders, George, Manager, Dorman Engineering Co., Mayorhold, Northampton.

1896. Sangster, Charles, Works Manager, Cycle Components Manufacturing Co., Bournbrook, Birmingham.

1896. Scanlan, Horace Edward, Beaconsfield, Longfleet, Poole.

1893. Schloesser, Robert, P.O., North Lyell, viâ Queenstown, Tasmania : (or care of Adolf Schloesser, 185 Sutherland Avenue, London, W.)

1897. Scott, Herbert Kilburn, Usina Wigg, Miguel Burnier, Minas, Brazil.

1897. Scott, Newton L., Kodak Works, Harrow.

1899. Scott, Robert, Superintendent Engineer, Laco Diamond Mining Co., Kroonstad, Orange Free State, South Africa.

1897. Scotter, Robert Herbert, Ormskirk and Southport Electric Light Railway, 55 Avondale Road, Southport.

1899. Secchi, Leopold, Sir W. G. Armstrong, Whitworth and Co., 8 Great George Street, Westminster, S.W.: and 62 Carminia Road, Balham, London, S.W.

1893. Segundo, Edward Carstensen de, 28 Victoria Street, Westminster, S.W.

1892. Seymour, William Frederick Earl, Engineer's Office, Great Western Railway, Swindon.

1897. Sharpley, George Ruston, Messrs. Ruston, Proctor and Co., Sheaf Iron Works, Lincoln.

1900. Shaw, William Campbell, 6 Ellerdale Road, Hampstead, London, N.W.

1899. Shawcross, George Nuttall, Lancashire and Yorkshire Railway, Horwich near Bolton.

1899. Sheffield, Frederick Gerard, Messrs. Laurence, Scott and Co., Gothic Works, Norwich.

1899. Shiba, Chuzaburo, 46 Sutherland Avenue, London, W.

1897. Shirtliff, Frederick, Messrs. Burn and Co., Howrah, Bengal, India.

1897. Sime, William, Messrs. Cook and Co., East London Soap Works, Bow, London, E.

1900. Simpson, Lightly Stapleton, Great Eastern Railway, Stratford, London, E.

1898. Simpson, Stephen, Messrs. Willey and Co., James Street Works, Exeter.

1899. Sirri, Lieutenant M., Engineering Department, Imperial Naval Arsenal, Constantinople.

1899. Slingsby, Walter, Messrs. Jonas Drake and Son, Ovenden, Halifax; and North View, Illingworth, Halifax.

1899. Smith, Francis Sumner, City of London Electric Lighting Co., 64 Bankside, London, S.E.

1899. Smith, Frederick Hugh, Babcock and Wilcox Co., 147 Queen Victoria Street, London, E.C.

1898. Smith, Herbert William, Works Manager, Messrs. Sydney Smith and Sons, Basford Brass Works, Nottingham; and Gordon Lodge, Easthorpe, Ruddington, Nottingham.

1900. Smith, John Smart, Jun., Harbour Engineer's Office, Aberdeen.

1891. Smith, Joseph Philip Grace, Polytechnic School of Engineering, 309 Regent Street, London, W.; and 8 Knatchbull Road, Willesden, London, N.W.

1897. Smith, Sidney, care of Messrs. George Findlay and Co., 21 Adderley Street, Cape Town, Cape Colony.

1898. Smith, Thomas John, Cannon Street, Hanley, Staffordshire.

1891. Smith, William Arthur, Midland Arches, Northampton; and 18 Albion Place, Northampton. [*Machinery, Northampton.*]

1898. Snow, John, Manager, Tasker's Engineering Co., New Station Road, Sheffield. [*Tasker, Sheffield.* 1005.]

1899. Somerville, Frederick Herbert, Messrs. Crompton and Co., Arc Works, Chelmsford.

1899. Speight, James William, Corporation Electricity Works, Blackpool.

1897. Spencer, Henry Wilmot, Messrs. J. S. White and Co., Engine Works, West Cowes, Isle of Wight.

1899. Spencer, Perceval, 5 Albert Terrace, Old Trafford, Manchester.

1899. Spiller, Claude, Gun-Carriage Factory, Madras, India.

1898. Statham, Frederick Benjamin, 188 Regent Road, Liverpool.

1900. Statham, Harry, 33 Rectory Road, Crumpsall, Manchester.

1899. Steinmetz, Arthur Samler Bernard, Messrs. West and Steinmetz, Commercial Road Foundry, Bedford. [*Castings, Bedford.*]

1899. Stephens, Charles Robert, Manager, Messrs. Stephens and Son, Ashfield, Falmouth. [*Stephens, Falmouth.* 10.]

1899. Stevens, Edwin Charles, Messrs. Archibald Smith and Stevens, Janus Works, Queen's Road, Battersea, London, S.W. [*Hydraulics, London. Battersea* 115.]

1896. Stewart, Charles Nigel, 22 and 23 Laurence Pountney Lane, London, E.C.

1896. Stobart, Henry Gervas, Wolsingham Steel Works, Wolsingham, near Darlington.

1899. Stocks, Harry Benwell, Messrs. G. and H. Hudson and Co., Savile Street East, Sheffield.

1898. Stockton, Cecil, Messrs. Richmond, Stockton and Co., Longton Iron Works, Staffordshire. [*Richmond, Longton.* 4117.]

1897. Stockton, Percy Sadler, The Woodlands, Langley Green, near Birmingham.

1898. Suffield, Charles Augustus, Birmingham Corporation Water Works, Elan Valley, Rhayader.

1897. Suffield, Frank Wilson, Empire Engineering Co., Failsworth, Manchester; and Glen Lyn, Grove Avenue, Moseley, Birmingham.

1900. Sutcliffe, Edgar Rouse, General Manager, Messrs. Herbert Alexander and Co., Queen's Engineering Works, Leeds.

1896. Sutherland, James, Manager, Alumina Factory, Larne Harbour, County Antrim, Ireland. [*Aluminium, Larne Harbour.*]

1894. Sutton, Hugh Reginald, Messrs. Mackies, Berks Iron Works, Caversham Road, Reading. [*Mackies, Reading.* 86.]

1896. Swallow, John, Messrs. W. Neill and Son, Bold Iron Works, St. Helens Junction, Lancashire. [*Neill, St. Helens.* 20.]

1887. Tabor, Edward Henry, Fennes, Braintree.

1893. Takatsuji, Narazo, Superintending Engineer, Calico Weaving Mill, Osaka, Japan.

1895. Takimura, Takeo, General Manager, Osaka Cotton Mill, Osaka, Japan.

1893. Talbot, Frederick William, Engineer and Manager, Water Works, Frimley Green, Farnborough, Hants.

1897. Talbot, William John, The Perfecta Tube Co., Aston, Birmingham.

1899. Taverner, Herbert Lacy, 12 Mosley Street, Newcastle-on-Tyne. [*Freezing. Newcastle-on-Tyne.*]

1897. Taylor, Arthur Joseph, 6 Apsley Crescent, Manningham, Bradford.

1898. Taylor, Edward, Jun., Messrs. Thomas and Taylor, 80 Lower Hillgate, Stockport.

1894. Taylor, William, Messrs. Taylor, Taylor and Hobson, Stoughton Street Works, Leicester. [*Lenses, Leicester.* 134.]

1899. Tennant, William John, Messrs. Boult, Wade and Kilburn, 111 Hatton Garden, London, E.C.

1893. Tenney, Dennis, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.

1899. Tester, William Andrews, Messrs. Robert W. Blackwell and Co., 39 Victoria Street, Westminster, S.W.

1898. Thain, William Arthur, Messrs. Francis Morton and Co., Garston, Liverpool; and 141 Moy Road, Cardiff.

1899. Thomas, Hubert Robert, Messrs. Edwin Richards and Sons, Portway Works, Wednesbury.

1900. Thomas, John Frederick Ivor, care of Dr. Alexander B. W. Kennedy 17 Victoria Street, Westminster, S.W.

1899. Thomas, Owen Powell, Messrs. Whittall and Co., Colombo, Ceylon.

1897. Thompson, Herbert, Messrs. Thompson Brothers, 111 Carver Street, Sheffield.

1896. Thompson, Thomas, 10 Maude Villas, Westcombe Hill, Blackheath, London, S.E.

1894. Thomson, Henry, Engineer, Cawnpore Woollen Mills, Cawnpore, India.

1893. Thomson, James Watson, Robert Gordon's College, Aberdeen.

1899. Thornycroft, John Edward, Messrs. John I. Thornycroft and Co., Church Wharf, Chiswick, London, W. [*Thornycroft, London.* 7306.]

1894. Thorpe, Walter Charles, Messrs. Goddard, Massey and Warner, Traffic Street, Nottingham.

1895. Threlfall, George, 50 Fenchurch Street, London, E.C. [*Gasify, London.*]

1898. Ticehurst, Hugh Gorham, Thames Ammunition Works, Erith, S.O., Kent; and Telham, Freta Road, Bexleyheath, Kent.

1893. Tomes, William Jameson, District Locomotive Superintendent, East Indian Railway, Jamalpur, Bengal, India: (or care of Joshua Tomes, 5 The Grove, Clacton-on-Sea.)

1893. Tomlinson, William Augustus, Kingston Terrace, Sleaford.

1896. Trafford, Alfred, Albion Lamp Works (Rippingille's), Birmingham; and Gravelly Hill, near Birmingham.

1899. Trunchion, William Thomas Fawdon, Messrs. Grafton and Co., Vulcan Works, Bedford.

1900. Turner, Frederick William, Messrs. E. R. and F. Turner, St. Peter's Iron Works, Ipswich. [*Gippeswyk, Ipswich.*]

1897. Turner, George Robert, Works Manager, Messrs. Ernest Scott and Mountain, Close Works, Newcastle-on-Tyne.

1893. Turner, Henry Arthur, care of Arthur Koppel, Peninsular House, Monument Street, London, E.C.

1896. Turner, James William, Messrs. George Smith and Co., 13 Commercial Road, Pimlico, London, S.W.

1900. Turner, William, Works Manager, Messrs. Davidson and Co., Sirocco Works, Bridge End, Belfast.

1896. Umney, Herbert Williams, 30 Woodside Road, London, S.E.

1898. Urquhart, Ridley James, 57 Barton Arcade, Manchester. [*Kinetic, Manchester.*]

1896. Vallint, Frank William, Superintendent, Mullicks Ghat Pumping Station, Calcutta Water Works, Calcutta, India.

1900. Venning, Albert John, Assistant Engineer R.N., H.M.S. "Hebe," Mediterranean Squadron.

1896. Vernon, William Harry, Messrs. E. Green and Son, Wakefield.

1892. Vezey, Albert Edward, Royal Palace Hotel, Kensington, London, W.

1893. Walker, Charles Christopher, Messrs. Walker, Eaton and Co., Wicker Iron Works, Sheffield. [*Founder, Sheffield.* 373.]

1899. Walker, William Peto, Vacuum Brake Co., 32 Queen Victoria Street, London. E.C.

1898. Ward, Frederick Arthur, care of J. C. Ward, 52 Queen Victoria Street, London, E.C.

1897. Ward, John Cecil, 52 Queen Victoria Street, London, E.C.

1892. Warton, Richard George Frank, P.O. Box 80, Umtali, Rhodesia, South Africa: (or care of Mrs. Warton, 12 Welsh Street, Chepstow.)

1895. Wasdell, Abel, Superintendent, Water Works, Allahabad, India.

1894. Wasdell, Thomas, City Water Works, Edgbaston, Birmingham.

1893. Watson, George, 39 Victoria Street, Westminster, S.W. [*Meterage, London.*]

1898. Waugh, Hylton Norman Drake, Locomotive Department, London Brighton and South Coast Railway, Brighton.

1897. Waynforth, Harry Morton, King's College, Strand, London, W.C.

1893. Wells, Sidney Herbert, Principal, Battersea Polytechnic Institute, Battersea, London, S.W.

1897. Welsh, John, P.O. Box 1421, Johannesburg, Transvaal, South Africa.

1899. West, Haarlem Ethneen, Snowshoe Mine, Libby, Montana, United States.

1899. Weston, George Cambridge, Kensington and Knightsbridge Electric Lighting Co., Kensington Court, London, W.

1897. Whale, Ralph Abrahams, Hampton Road, Pitsmoor, Sheffield.

1899. Wheeler, George Uzziah, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham.

1899. Wheeler, Oswald, India Rubber, Gutta Percha, and Telegraph Works Co. Silvertown, London, E.

1899. Whitehead, James Peter, Messrs. John M. Sumner and Co, 2 Brazennose Street, Manchester.

1899. Whitehouse, Alfred, Works Manager, New Rapid Cycle Co., Birmingham.

1898. Wigglesworth, Frank, Messrs. Croft and Perkins, Great Northern Works, Bradford.

1895. Wild, Adamson George, care of W. S. Laycock, Victoria Street Works, Sheffield.

1893. Wilkins, George Cornelius, Messrs. Vickers, Sons and Maxim, Naval Construction Works, Barrow-in-Furness.

1892. Williams, Arthur Edward, Cold Store, Daniel Adamson Road, Mode Wheel, Manchester.

1900. Williams, Charles Edward, Havelock Square, Sheffield; and Attlebro' House, Gell Street, Sheffield.

1899. Williams, Hal, 22 Eardley Crescent, Earl's Court, London, S.W.

1895. Williams, Henry Watson, Essex Street, Fremantle, Western Australia.

1899. Williams, John Ellacott, Metropolitan Electric Supply Co., Acton Lane, Willesden, London, N.W.; and Linacre, 37 Burgoyne Road, Harringay, London, N.

1900. Williams, Walter Doel, Messrs. Barry and Higham, 15 Great George Street, Westminster, S.W.

1899. Williamson, Edward, Messrs. W. Williamson and Co., Milborne Street, Well Street, Hackney, London, N.E. [*Washing Machines, London.*]

1889. Willis, Edward Turnley, Hockley Hall and Whateley Colliery, Tamworth; and Dost Hill, Tamworth.

1898. Wilson, Daniel Ellis, P.O. Box 152, Cairo, Egypt.

1898. Wilson, John Charles, Messrs. Guest and Chrimes, Rotherham; and 57 Moorgate, Rotherham.

1900. Winlaw, William Willoughby, Hill House, Morden, Mitcham.

1896. Winston, Harold Holmes, Messrs. Waterlow and Sons, Finsbury, London, E.C.

1896. Wiseman, Alfred, 54 Church Street, Birmingham. [*Verus, Birmingham.* 418.]

1898. Wolff, Charles Ernest, 96 Midland Road, Bedford.

1900. Wood, Charles, 22 Bridgewater Square, London, E.C.

1897. Worsley, Philip John, Jun., Messrs. Nettlefolds, Smethwick, Birmingham.

1895. Wort, Walter Edward, 8 Selsdon Road, West Norwood, London, S.E.

1889. Wright, Howard Theophilus, Broad Sanctuary Chambers, Westminster, S.W. [*Heaterite, London.* Westminster 248.]

1900. Wright, Richard Oliver, Henley's Telegraph Works, North Woolwich, London, E.

1898. Wrinch, Hugh Edward Hart, Engineer's Office, Chelsea Water Works, Surbiton.

1898. Wyman, Ronald, Messrs. Nettlefolds, Castle Works, Tydu, near Newport, Monmouthshire.

1899. Yeames, James Lamb, 53 Storey Square, Barrow-in-Furness.

1899. Young, Henry John, Messrs. H. Young and Co., Eccleston Iron Works, Pimlico, London, S.W.

1900. Young, Henry Wilson, 12 Camomile Street, London, E.C.

1899. Young, William, Engineer, London County Asylum, Sutton, Surrey.

ASSOCIATES.

1880. Allen, William Edgar, Imperial Steel Works, Tinsley, Sheffield.

1898. Appleby, Joseph, Managing Director, Messrs. Joseph Appleby, Tower Road, Aston, Birmingham. [*Bushes, Birmingham.* 2508.]

1881. Barcroft, Henry, Bessbrook Spinning Works, County Armagh, Ireland; and The Glen, Newry, Ireland.

1889. Barr, John, The Glenfield Engineering Works, Kilmarnock.

1898. Beanland, Fred, Messrs. Beanland, Perkin and Co., Leeds; and Bega, Harrogate.

1886. Bennison, William Clyburn, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield; and 12 Mayfield Road, Kersal, Manchester.

1890. Birch, John Grant, 10 and 11 Queen Street Place, London, E.C.

1892. Bowman, Frederic Hungerford, D.Sc., F.R.S.E., Mayfield, Knutsford.

1898. Brown, Ernest Frederick, Manager, Messrs. William Sugg and Co., Vincent Works, Regency Street, Westminster, S.W. [*Sugg, London.* Westminster 169.]; and John's Avenue, Hendon, London, N.W.

1888. Brown, Harold, Messrs. Linklater, Hackwood, Addison and Brown, 2 Bond Court, Walbrook, London, E.C.

1889. Castle, Frederick George, East London Technical College, People's Palace, Mile End Road, London, E.

1889. Chamberlain, John George, Messrs. Joseph Wright and Co., Neptune Forge, Tipton.

1888. Chrimes, Charles Edward, Messrs. Guest and Chrimes, Brass Works, Rotherham.

1890. Chubb, Richard, Messrs. Gillison and Chadwick, 10 Tower Buildings, Liverpool.

1879. Clowes, Edward Arnott, Messrs. William Clowes and Sons, Duke Street, Stamford Street, London, S.E. [*Clowes, London.* Hop 558.]

1895. Cole, James Conrad, 33 Cecile Park, Crouch End, London, N.

1892. Cooper, Thomas Lancelot Reed, Waterloo Chambers, 19 Waterloo Street, Glasgow.

1892. Cryer, Arthur, 10 Penywain Place, Roath Park, Cardiff.

1899. Dadge, Nelson, Messrs. P. C. Middleton and Co., 10 North St. Andrew Street, Edinburgh.

1893. Darlington, John, Engine, Boiler and Employers' Liability Insurance Co., 11 and 12 Albert Buildings, Queen Victoria Street, London, E.C.; and 3 Marlborough Gardens, Ealing, London, W.

1892. Davis, George Brown, Overton Lodge, Overton Road, Brixton, London, S.W.

1895. Docker, Frank Dudley, Messrs. Docker Brothers, Birmingham Varnish Works, Icknield Port Road, Birmingham. [*Japan, Birmingham.* 3522.]

1899. Douglas, Loudon McQueen, Baltic Wharf Engineering Works, Putney, London, S.W. [*Fluoroids, London.*]

1898. Dowlen, Walton Edward, 1238 Race Street, Denver, Colorado, United States.

1891. Foster, George, Hecla Foundry Steel Works, Sheffield; and Lyme Villa, Rotherham.

1889. Golby, Frederick William, 36 Chancery Lane, London, W.C.

1889. Gregory, George Francis, Boarzell, Hawkhurst.

1896. Harvey, Julius, 11 Queen Victoria Street, London, E.C. [*Crosshead, London.*]

1887. Hind, Enoch, Edgar Rise, Nottingham.

1898. Howard, Charles, British Non-Flammable Wood Co., Town Mead Road, Fulham, London, S.W.

1896. Hutton, William, P.O. Box 2399, Johannesburg, Transvaal, South Africa.

1891. Jackman, Joseph, Persberg Steel Works, Pothouse Road, Attercliffe, Sheffield. [*Persberg, Sheffield.* 94.]

1884. Jackson, Edward, Midland Railway-Carriage and Wagon Works, Birmingham. [*Wagon, Birmingham.*]

1897. James, Albert Alfred, St. George's Works, Paradise Street, West Bromwich. [*James, Wireworks, West Bromwich.* 5014.]

1896. Kennan, Williams Thomas, Messrs. Kennan and Sons, Fishamble Street, Dublin. [*Kennans, Dublin.*]

1897. Kenway, William Edward, Messrs. A. B. Bowden and Co., 17 Burlington Chambers, New Street, Birmingham.

1896. King, Benjamin Thomas, 163 Queen Victoria Street, London, E.C. [*Apis, London.* Bank 682.]

1898. Leechman, George Douglas, 18 Hertford Street, Coventry.

1896. Lemkes, Carl Rudolf Lewin, Messrs. Schäffer and Budenberg, 5 Wellington Street, Glasgow. [*Injector, Glasgow.* Royal 3119.]

1898. Light, George Miller, 32 Victoria Street, Westminster, S.W. [*Hurrah, London.* Westminster 502.]

1881. Lowood, John Grayson, Gannister Works, Attercliffe Road, Sheffield. [*Lowood, Sheffield.* 2030.]

1895. MacBrayne, Laurence, 119 Hope Street, Glasgow.

1886. Mackenzie, Keith Ronald, Gillotts, Henley-on-Thames.

1898. Marshall, Percival, Temple House, Temple Avenue, London, E.C.

1868. Matthews, Thomas Bright, Messrs. Turton Brothers and Matthews, Phœnix Steel Works, Sheffield. [*Matthews, Sheffield.*]

1889. McKinnel, William, 234A Nithsdale Road, Pollokshields, Glasgow.

1890. Meggitt, Samuel Newton, Messrs. Ibbotson Brothers and Co., Globe Steel Works, Sheffield.

1898. Meintjes, Laurens Schmitz, P.O. Box 148, Cape Town, Cape Colony.

1898. Murray-Morgan, Everard Home, Messrs. Bayliss, Jones and Bayliss, Victoria Iron Works, Wolverhampton.

1887. Neville, Edward Hermann, 35 Calle de Alcala, Madrid, Spain.

1874. Paget, Berkeley, Low Moor Iron Office, 2 Laurence Pountney Hill, Cannon Street, London, E.C. [*Gryphon, London.*]

1886. Peacock, William J. P., Wells Street, Oxford Street, London, W.; and 41 St. James' Street, London, S.W.

1888. Peake, Robert Cecil, Cumberland House, Redbourn, near St. Albans.

1887. Peech, Henry, Phœnix Bessemer Steel Works, near Sheffield; and 49 Victoria Street, Westminster, S.W.

1887. Peech, William Henry, Phœnix Bessemer Steel Works, near Sheffield; and Fernbank, Roehampton Park, London, S.W.

1894. Peters, Lindsley Byron, Messrs. G. D. Peters and Co., Moorgate Works, Moorfields, London, E.C. [*Peters, London.*]

1898. Phillipps, John, 52 Lincoln Road, Peterborough.

1884. Phillips, Richard Morgan (*Life Associate*), care of J. Griffin, 6 Algiers Road, Ladywell, London, S.E.

1891. Plant, George, Moseley Road School, Birmingham.

1897. Prior, James D., Eagle Range and Foundry Co., Catherine Street, Aston, Birmingham. [*Ranges, Birmingham.* 2558.]

1892. Reed, Ernest Charles, Raamsdonk, Holland.

1891. Rowcliffe, William Charles, 1 Bedford Row, London, W.C.

1899. Sachs, Edwin Otho, 3 Waterloo Place, Pall Mall, London, S.W.

1896. Sangster, William Skene, Superintendent, Lima Water Works, Lima, Peru.

1887. Scott, Walter, Victoria Chambers, Grainger Street West, Newcastle-on-Tyne. [*Contractor, Newcastle-on-Tyne.*]

1893. Simpson, Edward Percy, Messrs. Simpson and Co., 101 Grosvenor Road, Pimlico, London, S.W.

1899. Smith, George Robert, Yorkshire College, Leeds.

1897. Smith, William Henry, Manager, Platinotype Engineering Co., Platinotype Works, Penge, London, S.E.

1891. Spencer, Francis Henry, P.O. Box 1338, Johannesburg, Transvaal, South Africa.

1897. Starley, William, Queen Victoria Road, Coventry. [*Salvo, Coventry.* 72.]

1892. Stead, John Edward, 11 Queen's Terrace, Middlesbrough. [*Stead, Middlesbrough.*]

1890. Taylor, John, 99 and 101 Fonthill Road, Finsbury Park, London, N.; and Stockport.

1896. Taylor, Joseph Henry, 9 and 11 Fenchurch Avenue, London, E.C. [*Tyne, London.* Avenue 4108.]

1887. Tozer, Edward Sanderson, Phœnix Bessemer Steel Works, near Sheffield.

1893. Wadham, Arthur, Wardrobe Chambers, 146A Queen Victoria Street, London, E.C. [*Wadham, London.*]

1897. Wallach, Lewis Charles, 57 Gracechurch Street, London, E.C. [*Hammerman, London.*]

1898. Warner, Ashby William, Norton, Stockton-on-Tees.

1899. Waterlow, David Sydney, The Thorns, Northwood, near Rickmansworth, Herts.

1892. Whitehead, Richard David, Municipal Technical College, Green Hill, Derby.

1883. Williamson, Robert S., Cannock and Rugeley Collieries, Hednesford, near Stafford.

1899. Wilson, James Michael Graham, Messrs. R. Wilson, Son and Co., St. George's Street, Cape Town, Cape Colony.

1898. Wimpenny, Abel Buckley, Oak Villa, Hayfield, Stockport.

1891. Wiseman, Edmund, Cheapside and John Street, Luton. [*Wiseman, Luton.*]

1897. Wood, William Alfred, Messrs. Wood and Newland, 42 Spring Gardens, Manchester. [*Certificate, Manchester.*]

1899. Young, Johu Drummond, Managing Director, Scottish Boiler Insurance Co., 111 Union Street, Glasgow. [*Inspector, Glasgow.* 1271.]

GRADUATES.

1885. Addis, Frederick Henry, Mhow, Central India: (or care of Messrs. Grindlay and Co., 55 Parliament Street, London, S.W.)

1898. Albrecht, John August, 22 Eskdale Street, Crosshill, Glasgow.

1895. Alcock, Alfred Edwin, Messrs. Steel, Peech and Tozer, The Ickles, Rotherham.

1893. Alderson, Charles Albert Heselton, Norland House, Ramleh, Alexandria, Egypt.

1897. Allan, Frederick William, Glenalmond, Gillsland Road, Edinburgh.

1897. Allan, George, Jun., Courtlands, Gordon Road, Ealing, London, W.

1898. Allsebrook, Guthrie, 22 Lady Somerset Road, Kentish Town, London, N.W.

1897. Atherton, Percy William, City and Guilds of London Central Institution, Exhibition Road, London, S.W.

1890. Aubin, Percy Adrian, 29 St. James' Street, St. Helier's, Jersey

1888. Bailey, Wilfred Daniel, Messrs. Bailey Walker and Co., 454–456 Calle Cuyo, Buenos Aires, Argentine Republic.

1898. Balch, Bertram Duthoit, Ranmore, Birdhurst Road, Croydon.

1894. Barber, Edward Whitley, 42 Whitby Road, Fallowfield, Manchester.

1896. Barbosa, Agenor, Juiz de Fora, Minas Geraes, Brazil.

1889. Barrow, Arthur Robert Maclean, P. O. Box 39, Nelson, British Columbia: (or care of Mrs. Barrow, Holly Grove, Fittleworth, Pulborough.)

1897. Bartley, Bryan Cole, care of George C. T. Bartley, M.P., 57 Victoria Street, Westminster, S.W.

1897. Baxandall, Richard Fitzgerald, Cregneish, Ben Rhydding, Yorkshire.

1898. Bell, Frank, Signal Works, Engineer's Department, Midland Railway, Derby.

1884. Bell, Robert Arthur, Clevedon, Prestwich Park, Manchester.

1900. Bennett, Henry Arthur Dillon, Babcock and Wilcox Co., 147 Queen Victoria Street, London, E.C.

1895. Blair, George, 16 Albert Road (East), Crosshill, Glasgow.

1899. Blyth, Ernest Blackstone, Owen Stone Co., Bathgate, near Edinburgh.

1897. Bowden, John Horace, 17 Kempsford Gardens, Earl's Court, London, S.W.

1899. Bower, Henry Allan Richard, Globe and Phœnix Mines, Rhodesia, South Africa.

1888. Bradley, Arthur Ashworth, Princess Estate and Gold Mining Co., Roodepoort, near Johannesburg, Transvaal, South Africa: (or care of Rev. Gilbert Bradley, St. Edmund's Vicarage, Dudley, Worcestershire.)

1899. Bradley, Cecil Gustav, Borough Engineer's Office, Town Hall, Wolverhampton.

1887. Bremner, Bruce Laing, Assistant Locomotive Superintendent, Uganda Railway, Mombasa: (or care of Mrs. Bremner, Streatham, Canaan Lane, Edinburgh.)

1898. Bressey, Cyril Edward, Locomotive Department, Great Central Railway, Gorton, Manchester.

1890. Brousson, Robert Percy, Electric Traction Co., 16 Great George Street, Westminster, S.W.

1898. Bruce, John George, Messrs. Clarke, Chapman and Co., Gateshead; and 5 Ashbrooke Terrace, Sunderland.

1897. Bullock, Richard Cecil, Engineer's Office, West India Docks, London, E.

1899. Butters, Howard, Low Moor Iron Works, near Bradford.

1891. Caswell, Charles Henry, 75 Mount Pleasant, Barrow-in-Furness.

1890. Chatwood, Arthur Brunel, Chatwood's Safe and Lock Co., 76 Newgate Street, London, E.C. [*Chatwood, London.* Holborn 835.]

1900. Clapham, Thomas Alborn, Messrs. Clapham Brothers, Wellington Foundry, Keighley.

1895. Clarke, Leigh Theophilus, Electrical Department, Great Central Railway Woodford, Northants.

1892. Cleverly, William Bartholomew, 33 Ivydale Road, Nunhead, London, S.E.

1898. Close, Henry Alwyn, 56 Teall Street, Wakefield.

1892. Collingridge, Harvey, Messrs. S. Pearson and Son, Blackwall Tunnel Works, East Greenwich, London, S.E.; and Ingleborough, The Ridgway, Enfield.

1889. Cook, George Norcliffe, Messrs. Thomas Firth and Sons, Norfolk Works, Sheffield.

1899. Cooke, Rupert Thomas, Jun., Messrs. Francis Morton and Co., Garston, near Liverpool.

1900. Cooke, Stanley Walter, Thames Iron Shipbuilding and Engineering Works, Greenwich, London, S.E.

1899. Cotton, George Burchell, Town Hall Chambers, Torquay.

1896. Crow, Lewis, 9 East Lane, Ferguslie, Paisley.

1899. Cruickshank, George Seymour, Messrs. C. C. Humby and Co., P.O. Box 150, Kalgoorlie, Western Australia.

1898. Dare, Arthur Newman, Vacuum Oil Co., VI Theresienring 26, Budapest, Hungary.

1898. Davidson, John, Messrs. Browett, Lindley and Co., Patricroft, near Manchester; and 8 Trafford Road, Eccles.

1899. Davis, Harry Charles, care of Druitt Halpin, 17 Victoria Street, Westminster, S.W.

1896. Davson, Stephen Frederick, 203 Maida Vale, London, W.

1896. Dawe, John Nanscawen, care of Sir John Jackson, Admiralty Dockyard Extension, Keyham, Devonport.

1899. Dawson, John Edward, 3 Gloucester Terrace, Armley Road, Leeds.

1899. Dean, George, Lustleigh, Kingston Crescent, Portsmouth.

1898. Dickinson, John Gilbert, 69 Rice Lane, Egremont, Cheshire.

1899. Dimes, Charles William, Electric Resistance and Heating Co., 82 Victoria Street, Westminster, S.W.

1884. Dixon, John, 24 Formby Street, Formby, Liverpool.

1899. Dodge, Samuel Brickhill, Town Hall, Hove, Sussex.

1897. Donkin, Albert Henry, Jokai (Assam) Tea Co., Lahwal, Dibrugarh, Upper Assam, India.

1900. Down, Percy, Great Eastern Railway, Stratford Works, London, E.

1899. Drayton, Theophilus James Bradley, 64 Gipsy Hill, Upper Norwood, London, S.E.

1896. Dryden, William, Jun., Grimshaw Street Foundry, Preston.

1891. Duncan, Martin Gordon, Lexden, 63 Elmfield Road, Upper Tooting, London, S.W.

1899. Edwards, William Bernard, 57 Witton Road, Aston, Birmingham.

1898. Ellison, John, 9 Henry Street, Little Horton Lane, Bradford.

1899. Embleton, Charles Arnold, care of George Cawley, 29 Great George Street, Westminster, S.W.

1897. Emery, James Inman, Messrs. P. Orr and Sons, Mount Road, Madras, India.

1897. Engelbach, Charles Richard Fox, Sir W. G. Armstrong, Whitworth and Co., Elswick Works, Newcastle-on-Tyne.

1900. Epps, Laurence George John, 95 Upper Tulse Hill, London, S.W.

1897. Etlinger, George Ernest, Messrs. Boustead Brothers, Electrical Department, Colombo, Ceylon.

1900. Eyers, Cyril, London and North Western Railway, Crewe.

1895. Ferguson, Victor Bruce, Altidore Villa, Pittville, Cheltenham.

1896. Fiegehen, Edward George, Bedford Engineering Works, Bedford.

1899. Fletcher, Gerard Murray, Messrs. Hughes and Lancaster, Acrefair, Ruabon.

1897. Foster, Sydney, Engineer's Office, Lancashire and Yorkshire Railway, Fleetwood, R.S.O., Lancashire.

1897. Fox, Beaufoy Howard, 1 Belsize Road, South Hampstead, London, N.W.
1898. Fraser, William Stuart, Lancashire and Yorkshire Railway, Horwich, near Bolton.
1895. Fryer, Tom Jefferson, Brookdean, Hope, Sheffield.

1899. Gandon, Philip George, Egyptian Salt and Soda Co., Bulac, Cairo, Egypt.
1898. Gibb, Maurice Sylvester, Kingladores, Higham Road, Woodford, Essex.
1895. Gill, Charles Edgar, 9 Balmoral Place, Halifax.
1896. Goddard, William Herbert, Pinkthorne, Canning Road, Addiscombe, Croydon.
1897. Godson, Edward Harold, Cheadle House, Cheadle, Cheshire.
1899. Good, Basil Price, North Loudon Railway, Bow Road Works, London, E.; and 19 Luxemburg Gardens, Brook Green, Hammersmith, London, W.
1899. Goodall, Francis Harrison, Lucknow Avenue, Nottingham.
1898. Goodbehere, Alwyn, Messrs. Brooks and Doxey, Union Iron Works, West Gorton, Manchester.
1898. Goodbehere, Eric, Messrs. Brooks and Doxey, Union Iron Works, West Gorton, Manchester.
1899. Goodman, Frank Adolphus, Town Hall Chambers, Torquay.
1896. Gordon, Leslie, Bentley Priory, Stanmore.
1897. Goulding, Benjamin Joseph John, 39 Shandon Road, Clapham Common, London, S.W.
1898. Green, Harry Hewlett Richard, 46 Lillieshall Road, Clapham Common, London, S.W.
1899. Griffiths, Harold, Messrs. Parker, Wolverhampton; and Thornbury, Woodbourne Road, Edgbaston, Birmingham.
1897. Guthrie, William James, Templehill, Troon.

1899. Hale, Harold, Electrical Engineer's Office (Waterloo and City Railway), London and South Western Railway, Launcelot Street, London, S.E.
1895. Hall, William Brasier, 10 Colosseum Terrace, Albany Street, London, N.W.
1898. Hamilton, Harold, Messrs. Thomas Hamilton and Co., 90 Cannon Street, London, E.C.
1898. Hammond, Robert Whitehead, 64 Victoria Street, Westminster, S.W.
1899. Harris, Francis Graham Reynolds, Messrs. Bramwell and Harris, 5 Great George Street, Westminster, S.W.
1898. Harris, Henry Evans, Messrs. Massey and Co., Madras, India.
1898. Haslam, Alfred Victor, Union Foundry, Derby.
1899. Hawkins, Elyot Sydney, Locomotive Department, Cambrian Railways, Oswestry.

1889. Hayward, Robert Francis, Union Light and Power Co., Salt Lake City, Utah, United States.

1877. Heaton, Arthur, Messrs. Heaton and Dugard, Metal and Wire Works, Shadwell Street, Birmingham. [*Heagard, Birmingham.*]

1899. Hemingway, Leigh, Great Western Railway, Stafford Road, Wolverhampton.

1900. Higgs, Arthur Franklin, Clarence House, Gloucester.

1891. Hodgson, William James, Messrs. Hodgson and Hodgson, Central Chemical Works, Nottingham.

1887. Hogg, William, Messrs. Gates and Thomas, Warrington.

1898. Homan, Brees van, Messrs. Homan and Rodgers, 17 Gracechurch Street, London, E.C.

1889. Hosgood, Thomas Watkin, Eaton Grove, Swansea.

1889. Howard, Geoffrey, Britannia Iron Works, Bedford.

1883. Howard, Harry James, Messrs. Colman's Mustard Mills, Carrow Works, Norwich.

1900. Hughes, Edmund Selby, Providence Wharf, East Greenwich, London, S.E.

1891. Hughes, Edward Sinclair Bremner, 1 The Terrace, Thurlow Park Road, West Norwood, London, S.E.

1896. Humphrey, Frederick George, 166 High Street, Sevenoaks.

1900. Hunton, William, St. Cuthberts, Bath.

1899. Hutchison, Percy, Babcock and Wilcox Co., 147 Queen Victoria Street, London, E.C.

1896. Johnson, Henry Howard, Woodville, Rondebosch, Cape Town, Cape Colony.

1891. Jordan, Frederic William, 42 Wells Street, Mortimer Street, Cavendish Square, London, W.

1900. Josselyn, Edward, Messrs. A. Ransome and Co., Stanley Works, Chelsea, London, S.W.

1895. Keen, Harry A., Patent Nut and Bolt Co., London Works, near Birmingham.

1898. Kenrick, Archibald, Jun., Messrs. Joshua Buckton and Co., Well House Foundry, Meadow Road, Leeds.

1899. Kimber, Harry Watkins, Messrs. Bramwell and Harris, 5 Great George Street, Westminster, S.W.

1896. Kitsell, Archibald Edward, 24 St. Stephen's Avenue, Shepherd's Bush, London, W.

1883. Lander, Philip Vincent, Woodside House, Wimbledon: (or care of W. W. Lander, Imperial Ottoman Bank, 26 Throgmorton Street, London, E.C.)

1898. Langdon, Harold Arthur William, Locomotive Department, Midland Railway, Kentish Town, London, N.W.

1900. Lee, Walter, 38 Worple Road, Wimbledon.

1886. Lewis, William Thomas, Jun., Engineer's Office, Bute Docks, Cardiff; and Bronrhiw, Caerphilly, near Cardiff.

1897. Locket, Athol, Panitola, Dibrugarh, Assam, India.

1899. Lowsley, Sydney Evan, Borough Engineer's Office, Town Hall, Wolverhampton.

1883. Mackenzie, Thomas Brown, Messrs. David Colville and Sons, Dalzell Steel and Iron Works, Motherwell; and 342 Duke Street, Glasgow.

1893. Mackesy, Walter, 37 Worley Avenue, Low Fell, Gateshead.

1897. Mansfield, Frank, Messrs. Mansfield and Sons, 9 Second Line Beach, Madras, India. [*Gaslight, Madras.*]

1899. Mansfield, Oliver, Messrs. Edwin Mansfield and Sons, Moorgate Station Chambers, London, E.C.

1868. Mappin, Frank, Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield.

1898. Maria, Horacio Santa, Administracion del Gas, Rosario de Santa Fé, Argentine Republic: (or care of Messrs. Hugo Brown and Co., 18 Alexandra Buildings, Ormond Street, Liverpool.)

1892. Marks, Alfred Pally, 55 Gillott Road, Birmingham.

1895. Marriner, John, Park View, Crooms Hill, Greenwich, London, S.E.

1899. Marsden, Alfred, 27 Camera Square, Beaufort Street, Chelsea, London, S.W.

1889. Marshall, Frank Theodore, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1896. Marshall, John Frederick, King's College, Cambridge.

1888. Marten, Hubert Bindon, Contractor's Office, Breydon Viaduct, Great Yarmouth; and Pedmore, Stourbridge.

1886. Mattos, Alvaro Gomes de, 98 Rua da Saude, Rio de Janeiro, Brazil: (or care of Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.)

1898. Mayes, Howard, Kelvedon, Westwood Park, Southampton.

1899. Mayo, William Henry, Coventry Cycle and Motor Co., Church Street, Malvern.

1900. McDermott, Hugh, 3 Thurleigh Road, Wandsworth Common, London, S.W.

1892. Miles, Frederick Hudson, Assistant Locomotive Superintendent, North Western Railway, Lahore, India.

1900. Miller, William Thomas Ward, Messrs. Askham Brothers and Wilson, Yorkshire Steel Works, Napier Street, Sheffield.

1891. Mills, Matthew William, Moss Foundry, Heywood, near Manchester.

1891. Mogg, Henry Hodges, Newbridge Hill, near Bath.

1897. Montgomery, Charles Hubert, Lancashire and Yorkshire Railway, Normanton, Yorkshire.

1900. Moraes, James Affleck, Surveyor's Office, Sandgate, Kent.

1900. Morgan, David James, 18 Emma Place, Stonehouse, Plymouth.

1896. Morton, John Henry, Locomotive Department, Ferro Carril del Sud, Buenos Aires, Argentine Republic.

1897. Muggeridge, Harold Chisman, Engineering Workshops, South Indian Railway, Trichinopoly, India.

1892. Murray, David James, 101 Forth Street, Pollokshields, Glasgow.

1897. Nixon, Charles Basil, 38 Bidston Road, Birkenhead.

1899. Nutter, Harold Norman, Messrs. Aykroyd and Sons, Oakwood Dye Works, Bradford.

1899. O'Brien, Henry Eoghan, Lancashire and Yorkshire Railway, Horwich, near Bolton.

1883. O'Connor, John Frederick, Messrs. O'Connor and Rutherford, 31 and 33 Broadway, New York, United States.

1883. Osborn, William Fawcett, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield.

1899. Parsonage, William Rawlett, Cleevedale, Birchwood Crescent, Sparkbrook, Birmingham.

1899. Pashby, Arthur Harold, Messrs. Burstall and Monkhouse, 14 Old Queen Street, Westminster, S.W.

1898. Payne, Frank Gervas, Stettin Lodge, St. Faith's Road, West Norwood, London, S.E.

1899. Pearson, Charles Dearne, 27 Great George Street, Westminster, S.W.

1899. Peregrine, William Henry, Manchester Road, Bury, Lancashire.

1890. Philipson, John, Messrs. Atkinson and Philipson, 27 Pilgrim Street, Newcastle-on-Tyne. [*Carriage, Newcastle-on-Tyne.* 1641.]

1884. Philipson, William, Messrs. Atkinson and Philipson, 27 Pilgrim Street, Newcastle-on-Tyne. [*Carriage, Newcastle-on-Tyne.* 1641.]

1898. Phillips, Walter Patrick Frear, London United Tramways, 88 High Road, Chiswick, London, W.

1899. Philpot, Harold Percy, Messrs. Yarrow and Co., Isle of Dogs, Poplar, London, E.

1899. Pointon, John Edward, Messrs. Lewis and Pointon's Panification, Wellington, Shropshire.

1890. Powell, Frederick, York House, Malvern Link, Malvern.

1899. Powell, William Foster, Works Manager, Messrs. H. J. Lloyd and Co., Petergate, York.

1892. Power, Arthur Cyril, 17 Fordwych Road, Brondesbury, London, N.W.

1898. Preen, Arthur Harvey, 47 Victoria Street, Westminster, S.W.

1899. Pritchard, Roger Cromwell, 55 Highbury New Park, London, N.

1899. Prosser, Robert Walter Ostell, Blaydon Iron Works, Blaydon-on-Tyne.

1897. Pullar, Frederick Pattison, Messrs. Robert Pullar and Sons, Keirfield, Bridge of Allan, N.B.

1897. Rainforth, William Frederick, Messrs. Ruston, Proctor and Co., Sheaf Iron Works, Lincoln.

1892. Ransom, Herbert Byrom, Messrs. Manlove Alliott and Co., 57 Gracechurch Street, London, E.C.

1900. Rasey, Alfred Ernest, City and South London Railway Extension, 7 Denman Street, London, S.E.

1898. Rennie, John Assheton, Messrs. G. Rennie and Co., Thames Street, Greenwich, London, S.E.

1884. Reynolds, Thomas Blair, 28 Victoria Street, Westminster, S.W.

1895. Riches, Carlton Tom Hurry, 8 Park Grove, Cardiff.

1892. Ridley, James Cartmell, Jun., Swalwell Steel Works, Newcastle-on-Tyne.

1898. Roberts, Frederick Edward Laing, Tydebrook Vicarage, Wadhurst, Sussex.

1898. Roberts, Herbert Edward, 6 Richmond Terrace, Port Talbot.

1899. Roberts, Robert Coryton, Messrs. John Fowler and Co., Leeds.

1897. Robinson, Herbert, 16 Markham Square, Chelsea, London, S.W.

1897. Rootham, Howard Melville, 11 Deronda Road, Herne Hill, London, S.E.

1900. Rosevere, Reginald George, Locomotive Department, Midland Railway, Derby.

1896. Rothschild, Lester Vivian, 80 Lancaster Gate, London, W.

1888. Rümmele, Alfredo, 17 Via Principe Umberto, Milan, Italy.

1894. Russell, William Colin, 42 Arodene Road, Brixton Hill, London, S.W.

1899. Sanderson, Herbert William, University College, Nottingham; and Bath Vale, Mansfield.

1890. Saxelby, Herbert Raffaelle, care of C. Aris, 19 Binden Road, Ravenscourt Park, London, W.

1892. Scarfe, George Norman, care of George Scarfe, Gawler Place, Adelaide, South Australia.

1899. Schontheil, Theodore, Messrs. Robert W. Blackwell and Co., 39 Victoria Street, Westminster, S.W.

1881. Scott, Ernest, Messrs. Ernest Scott and Mountain, Close Works, Newcastle-on-Tyne. [*Esco, Newcastle-on-Tyne.* 1259.]

1898. Sharp, William, Messrs. Redpath, Brown and Co., St. Andrew Steel Works, Edinburgh.

1892. Shepherd, James Horace, Great Western Railway, Swindon; and 11 Gloucester Street, Swindon.

1896. Simpson, Norman De Lisle, Bournanston Pumping Station. Water Works Department, Barbados, West Indies.

1895. Smith, Frederick Hardcastle, Steam Crane Works, Old Foundry, Rodley, near Leeds.

1898. Smith, George Alfred, Whessoe Foundry Co., Darlington.

1898. Smith, Ralph Vernon, Messrs. Sydney Smith and Sons, Basford Brass Works, Nottingham.

1899. Smith, Raymond Berkeley, Royal School of Mines, South Kensington, London, S.W.

1900. Smyth, Robert Henry, Glenmore Works, Coolaney, Co. Sligo, Ireland.

1898. Stanley, Harry Frank, Jun., 111 Stirling Street, New Clee, Great Grimsby.

1899. Stevens, Percy Herbert, Messrs. Archibald Smith and Stevens, Janus Works, Queen's Road, Battersea, London, S.W.

1899. Stewart, Charles, Great Northern Railway Works, Doncaster.

1892. Stokes, Frank Torrens, East Rand Proprietary Mines, P.O. Box 295, Cape Town, Cape Colony.

1900. Stonebridge, Arthur Watson. Water Engineer's Department, New Road, Portland.

1899. Stow, George, care of C. O. Blaber, 64 Ship Street, Brighton.

1898. Strong, Alfred George, Norfolk Works, St. Paul's, Bristol.

1885. Tangye, John Henry, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham.

1899. Tarling, Thomas, St. John del Rey Mines, Morro Velho, Minas Geraes, Brazil.

1898. Tarver, Herbert Henry, care of Messrs. J. H. Vavasseur and Co., Colombo, Ceylon.

1898. Taylor, Charles Percy, Messrs. Knight, Bevan and Sturge, Northfleet, Kent.

1899. Taylor, Frank Coston, Lancashire and Yorkshire Railway, Horwich, near Bolton.

1884. Taylor, Maurice, 39 Rue de Lisbonne, Paris.

1896. Thom, Frank, Messrs. Yates and Thom, Canal Foundry, Blackburn.

1899. Thomson, Alfred Morris, Lilybank Engine and Boiler Works, Dundee.

1894. Thorpe, Wilfred Bertram, 20 Larkhall Rise, Clapham, London, S.W.

1895. Titren, Gerald Ernest de Keyser, Natal Government Railway Works, Durban, Natal.

1899. Trafford, Joseph Peter, Gravelly Hill, near Birmingham.

1899. Tregoning, Wynn Harold, Messrs. Bramwell and Harris, 5 Great George Street, Westminster, S.W.

1898. Turner, Vincent, City Water Engineer's Office, Town Hall, Wakefield.

1898. Vaughan, John Crake, Wraxall, near Bristol.

1888. Waddington, Samuel Sugden, 35 King William Street, London Bridge, London, E.C.

1897. Wade, Francis Richard, 57 Strathblaine Road, St. John's Hill, London, S.W.

1900. Wadham, Robert, 146A Queen Victoria Street, London, E.C.

1896. Walker, Charles Bell, Messrs. Veritys, Plume Works, Aston, Birmingham.

1898. Walker, Robert Hugh, Messrs. T. Middleton and Co., Loman Street, Southwark, London, S.E.

1900. Walton, Denys, 3 Whittingstall Road, Fulham, London, S.W.

1898. Wans, Oswald, Messrs. Bryan Donkin and Co., 55 Southwark Park Road, Bermondsey, London, S.E.; and Easdale, Westcombe Park Road, Blackheath, London, S.E.

1898. Wardle, Frank Harold, 10 Forest Road East, Nottingham.

1888. Waring, Henry, Engineer, Dublin Laundry Co., Milltown, near Dublin.

1900. Warner, James Sutherland, Leecoll Electric Co., New Norfolk Street, Shoreditch, London, E.

1899. Warren, Robert Augustus, Locomotive Department, Lancashire and Yorkshire Railway, Newton Heath, Manchester.

1886. Wesley, Joseph A., Messrs. Woodhouse and Rixson, Chantrey Steel and Crank Works, Sheffield.

1900. Western, Hugh, Egyptian State Railway, Cairo, Egypt.

1888. Whichello, Richard, Messrs. Max Nothmann and Co., Rio de Janeiro, Brazil: (or 44 Trumpington Street, Cambridge.)

1900. Widdowson, Ernest Leedham, Messrs. Jonas Drake and Son, Ovenden, Halifax.

1889. Wigham, John Cuthbert, Edmundsons' Electricity Corporation, Broad Sanctuary Chambers, Westminster, S.W.

1895. Wilkin, Ernest Vivian, Northumberland Engine Works, Wallsend-on-Tyne; and 11 Appold Street, Finsbury, London, E.C.
1898. Williams, Norman C., Messrs. Babcock and Wilcox, 147 Queen Victoria Street, London, E.C.
1900. Williams, Vernon Ingram Norbury, 75 Shakespeare Street, Chorlton-on-Medlock, Manchester.
1890. Wilson, Alexander Cowan, Osgathorpe Hills, Sheffield.
1897. Wilson, Robert James, 228 Goldhawk Road, London, W.
1899. Wray, Romulus Paul, 42 Tollington Road, Holloway, London, N.
1890. Wright, William Carthew, Mary Street, Charters Towers, Queensland.
1898. Wylie, Reginald Charlton, School of Mines, Camborne.

1891. Yerbury, Frederick Augustus, Worthington Pumping Engine Co., 153 Queen Victoria Street, London, E.C.; and 21 Tudor Road, Kingston-on-Thames.

THE INSTITUTION OF MECHANICAL ENGINEERS.

Memorandum of Association.

AUGUST 1878.

1st. The name of the Association is "THE INSTITUTION OF MECHANICAL ENGINEERS."

2nd. The Registered Office of the Association will be situate in England.

3rd. The objects for which the Association is established are :—

(A.) To promote the science and practice of Mechanical Engineering and all branches of mechanical construction, and to give an impulse to inventions likely to be useful to the Members of the Institution and to the community at large.

(B.) To enable Mechanical Engineers to meet and to correspond, and to facilitate the interchange of ideas respecting improvements in the various branches of mechanical science, and the publication and communication of information on such subjects.

(C.) To acquire and dispose of property for the purposes aforesaid.

(D.) To do all other things incidental or conducive to the attainment of the above objects or any of them.

4th. The income and property of the Association, from whatever source derived, shall be applied solely towards the promotion of the objects of the Association as set forth in this Memorandum of Association, and no portion thereof shall be paid or transferred directly or indirectly, by way of dividend, bonus, or otherwise howsoever, by way of profit to the persons who at any time are or have been Members of the Association, or to any of them, or to any person claiming through any of them: Provided that nothing herein contained shall prevent the payment in good faith of remuneration to any officers or servants of the Association, or to any Member of the Association, or other person, in return for any services rendered to the Association, or prevent the giving of privileges to the Members of the Association in attending the meetings of the Association, or prevent the borrowing of money (under such powers as the Association and the Council thereof may possess) from any Member of the Association, at a rate of interest not greater than five per cent. per annum.

5th. The fourth paragraph of this Memorandum is a condition on which a licence is granted by the Board of Trade to the Association in pursuance of Section 23 of the Companies Act 1867. For the purpose of preventing any evasion of the terms of the said fourth paragraph, the Board of Trade may from time to time, on the application of any Member of the Association, impose further conditions, which shall be duly observed by the Association.

6th. If the Association act in contravention of the fourth paragraph of this Memorandum, or of any such further conditions, the liability of every Member of the Council shall be unlimited; and the liability of every Member of the Association who has received any such dividend, bonus, or other profit as aforesaid, shall likewise be unlimited.

7th. Every Member of the Association undertakes to contribute to the Assets of the Association in the event of the same being wound up during the time that he is a Member, or within one

year afterwards, for payment of the debts and liabilities of the Association contracted before the time at which he ceases to be a Member, and of the costs, charges, and expenses for winding up the same, and for the adjustment of the rights of the contributories amongst themselves, such amount as may be required not exceeding Five Shillings, or in case of his liability becoming unlimited such other amount as may be required in pursuance of the last preceding paragraph of this Memorandum.

8th. If upon the winding up or dissolution of the Association there remains, after the satisfaction of all its debts and liabilities, any property whatsoever, the same shall not be paid to or distributed among the Members of the Association, but shall be given or transferred to some other Institution or Institutions having objects similar to the objects of the Association, to be determined by the Members of the Association at or before the time of dissolution; or in default thereof, by such Judge of the High Court of Justice as may have or acquire jurisdiction in the matter.

Articles of Association.

February 1893.

INTRODUCTION.

Whereas an Association called "The Institution of Mechanical Engineers" existed from 1847 to 1878 for objects similar to the objects expressed in the Memorandum of Association of the Association (hereinafter called "the Institution") to which these Articles apply;

And whereas the Institution was formed in 1878 for furthering and extending the objects of the former Institution, by a registered Association, under the Companies Acts 1862 and 1867;

And whereas terms used in these Articles are intended to have the same respective meanings as they have when used in those Acts, and words implying the singular number are intended to include the plural number, and *vice versâ*;

Now therefore it is hereby agreed as follows:—

CONSTITUTION.

1. For the purpose of registration the number of members of the Institution is unlimited.

MEMBERS, ASSOCIATE MEMBERS, GRADUATES, ASSOCIATES, AND HONORARY LIFE MEMBERS.

2. The present Members of the Institution, and such other persons as shall be admitted in accordance with these Articles, and none others, shall be Members of the Institution, and be entered on the register as such.

3. Any person may become a Member of the Institution who shall be qualified and elected as hereinafter mentioned, and shall agree to become such Member, and shall pay the entrance fee and first subscription accordingly.

4. The qualification of Members shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

5. The election of Members shall be conducted as prescribed by the By-laws from time to time in force, as provided by the Articles.

6. In addition to the persons already admitted as Graduates, Associates, and Honorary Life Members respectively, the Institution may admit such persons as may be qualified and elected in that behalf as Associate Members, Graduates, Associates, and Honorary Life Members respectively of the Institution, and may confer upon them such privileges as shall be prescribed by the By-laws from time to time in force, as provided by the Articles: provided that no Associate Member, Graduate, Associate, or Honorary Life Member shall be deemed to be a Member within the meaning of the Articles.

7. The qualification and mode of election of Associate Members, Graduates, Associates, and Honorary Life Members shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

8. The rights and privileges of every Member, Associate Member, Graduate, Associate, or Honorary Life Member shall be personal to himself, and shall not be transferable or transmissible by his own act or by operation of law.

ENTRANCE FEES AND SUBSCRIPTIONS.

9. The Entrance Fees and Subscriptions of Members, Associate Members, Graduates, and Associates shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

EXPULSION.

10. If any Member, Associate Member, Graduate, or Associate shall leave his subscription in arrear for two years, and shall fail to pay such arrears within three months after a written application has been sent to him by the Secretary, his name may be struck off the register by the Council at any time afterwards, and he shall thereupon cease to have any rights as a Member, Associate Member, Graduate, or Associate, but he shall nevertheless continue liable to pay the arrears of subscription due at the time of his name being so struck off: provided always that this regulation shall not be construed to compel the Council to remove any name, if they shall be satisfied the same ought to be retained.

11. The Council may refuse to continue to receive the subscriptions of any person who shall have wilfully acted in contravention of the regulations of the Institution, or who shall in the opinion of the Council have been guilty of such conduct as shall have rendered him unfit to continue to belong to the Institution; and may remove his name from the register, and he shall thereupon cease to be a Member, Associate Member, Graduate, or Associate (as the case may be) of the Institution.

GENERAL MEETINGS.

12. The General Meetings shall consist of the Ordinary Meetings, the Annual General Meeting, and of Special Meetings as hereinafter defined.

13. The Annual General Meeting shall take place in London in one of the first four months of every year. The Ordinary Meetings shall take place at such times and places as the Council shall determine.

14. A Special Meeting may be convened at any time by the Council, and shall be convened by them whenever a requisition signed by twenty Members or Associate Members of the Institution,

specifying the object of the Meeting, is left with the Secretary. If for fourteen days after the delivery of such requisition a Meeting be not convened in accordance therewith, the Requisitionists or any twenty Members or Associate Members of the Institution may convene a Special Meeting in accordance with the requisition. All Special Meetings shall be held in London.

15. Seven clear days' notice of every Meeting, specifying generally the nature of any special business to be transacted at any Meeting, shall be given to every person on the register of the Institution, except as provided by Article 35, and no other special business shall be transacted at such Meeting; but the non-receipt of such notice shall not invalidate the proceedings of such Meeting. No notice of the business to be transacted (other than such ballot lists as may be requisite in case of elections) shall be required in the absence of special business.

16. Special business shall include all business for transaction at a Special Meeting, and all business for transaction at every other Meeting, with the exception of the reading and confirmation of the Minutes of the previous Meeting, the election of Members, Associate Members, Graduates, and Associates, and the reading and discussion of communications as prescribed by the By-laws, or by any regulations of the Council made in accordance with the By-laws.

PROCEEDINGS AT GENERAL MEETINGS.

17. Twenty Members or Associate Members shall constitute a quorum for the purpose of a Meeting other than a Special Meeting. Thirty Members or Associate Members shall constitute a quorum for the purpose of a Special Meeting.

18. If within thirty minutes after the time fixed for holding the Meeting a quorum is not present, the Meeting shall be dissolved, and all matters which might, if a quorum had been present, have been done at a Meeting (other than a Special Meeting) so dissolved may forthwith be done on behalf of the Meeting by the Council.

19. The President shall be Chairman at every Meeting, and in his absence one of the Vice-Presidents; and in the absence of all Vice-Presidents a Member of Council shall take the chair; and if no Member of Council be present and willing to take the chair, the Meeting shall elect a Chairman.

20. The decision of a General Meeting shall be ascertained by show of hands, unless, after the show of hands, a poll is forthwith demanded; and by a poll, when a poll is thus demanded. The manner of taking a show of hands or a poll shall be in the discretion of the Chairman; and an entry in the Minutes, signed by the Chairman, shall be sufficient evidence of the decision of the General Meeting. Each Member and Associate Member shall have one vote and no more. In case of equality of votes the Chairman shall have a second or casting vote: provided that this Article shall not interfere with the provisions of the By-laws as to election by ballot.

21. The acceptance or rejection of votes by the Chairman shall be conclusive for the purpose of the decision of the matter in respect of which the votes are tendered: provided that the Chairman may review his decision at the same Meeting, if any error be then pointed out to him.

BY-LAWS.

22. The By-laws set forth in the schedule to these Articles, and such altered and additional By-laws as shall be substituted or added as hereinafter mentioned, shall regulate all matters by the Articles left to be prescribed by the By-laws, and all matters which consistently with the Articles shall be made the subject of By-laws. Alterations in, and additions to, the By-laws, may be made only by resolution of the Members and Associate Members at an Annual General Meeting, after notice of the proposed alteration or addition has been announced at the previous Ordinary Meeting, and not otherwise.

COUNCIL.

23. The Council of the Institution shall be chosen from the Members only, and shall consist of one President, six Vice-Presidents, fifteen ordinary Members of Council, and of the Past-Presidents. The President, two Vice-Presidents, and five Members of Council (other than Past-Presidents), shall retire at each Annual General Meeting, but shall be eligible for re-election. The Vice-Presidents and Members of Council to retire each year shall, unless the Council agree among themselves, be chosen from those who have been longest in office, and in cases of equal seniority shall be determined by ballot.

24. The election of a President, Vice-Presidents, and Members of Council, to supply the place of those retiring at the Annual General Meeting, shall be conducted in such manner as shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

25. The Council may supply any casual vacancy in the Council (including any casual vacancy in the office of President) which shall occur between one Annual General Meeting and another; and the President, Vice-Presidents, or Members of Council so appointed by the Council shall retire at the succeeding Annual General Meeting. Vacancies not filled up at any such Meeting shall be deemed to be casual vacancies within the meaning of this Article.

OFFICERS.

26. The Treasurer, Secretary, and other employés of the Institution shall be appointed and removed in the manner prescribed by the By-laws from time to time in force, as provided by the Articles. Subject to the express provisions of the By-laws, the officers and servants of the Institution shall be appointed and removed by the Council.

27. The powers and duties of the officers of the Institution shall, subject to any express provision in the By-laws, be determined by the Council.

POWERS AND PROCEDURE OF COUNCIL.

28. The Council may regulate their own procedure, and delegate any of their powers and discretions to any one or more of their body, and may determine their own quorum: if no other number is prescribed, three members of Council shall form a quorum.

29. The Council shall manage the property, proceedings, and affairs of the Institution, in accordance with the By-laws from time to time in force.

30. The Treasurer may, with the consent of the Council, invest in the name of the Institution any moneys not immediately required for the purposes of the Institution in or upon any of the following investments (that is to say):—

(A) The Public Funds, or Government Stocks of the United Kingdom, or of any Foreign or Colonial Government guaranteed by the Government of the United Kingdom.

(B) Real or Leasehold Securities, or in the purchase of real or leasehold properties in Great Britain or Ireland.

(C) Debentures, Debenture Stock, or Guaranteed or Preference Stock, of any Company incorporated by special Act of Parliament, the ordinary Shareholders whereof shall at the time of such investment be in actual receipt of half-yearly or yearly dividends.

(D) Stocks, Shares, Debentures, or Debenture Stock of any Railway, Canal, or other Company, the undertaking whereof is leased to any Railway Company at a fixed or fixed minimum rent.

(E) Stocks, Shares, or Debentures of any East Indian Railway or other Company, which shall receive a contribution from Her Majesty's East Indian Government of a fixed annual percentage on their capital, or be guaranteed a fixed annual dividend by the same Government.

(F) The security of rates levied by any corporate body empowered to borrow money on the security of rates, where such borrowing has been duly authorised by Act of Parliament.

31. The Council may, with the authority of a resolution of the Members and Associate Members in General Meeting, borrow moneys for the purposes of the Institution on the security of the property of the Institution, or otherwise at their discretion.

32. No act done by the Council, whether *ultra vires* or not, which shall receive the express or implied sanction of the Members and Associate Members in General Meeting, shall be afterwards impeached by any member of the Institution on any ground whatsoever, but shall be deemed to be an act of the Institution.

NOTICES.

33. A notice may be served by the Council upon any Member, Associate Member, Graduate, Associate, or Honorary Life Member, either personally or by sending it through the post in a prepaid letter addressed to him at his registered place of abode.

34. Any notice, if served by post, shall be deemed to have been served at the time when the letter containing the same would be delivered in the ordinary course of the post; and in proving such service it shall be sufficient to prove that the letter containing the notice was properly addressed and put into the post office.

35. No Member, Associate Member, Graduate, Associate, or Honorary Life Member, not having a registered address within the United Kingdom, shall be entitled to any notice; and all proceedings may be had and taken without notice to such member, in the same manner as if he had had due notice.

By-laws.

(*Last Revision, February* 1894.)

MEMBERSHIP.

1. Candidates for admission as Members must be persons not under twenty-five years of age, who, having occupied during a sufficient period a responsible position in connection with the practice or science of Engineering, may be considered by the Council to be qualified for election.

2. Candidates for admission as Associate Members must be persons not under twenty-five years of age, who, being engaged in such work as is connected with the practice or science of Engineering, may be considered by the Council to be qualified for election, though not yet to occupy positions of sufficient responsibility, or otherwise not yet to be eligible, for admission as Members. They may afterwards be transferred at the discretion of the Council to the class of Members.

3. Candidates for admission as Graduates must be persons holding subordinate situations, and not under eighteen years of age. They must furnish evidence of training in the principles as well as in the practice of Engineering. Before attaining the age of twenty-six years, those elected after 1892 must apply for election as Members, Associate Members, or Associates, if they desire to remain connected with the Institution; they may not continue Graduates after attaining the age of twenty-six.

4. Candidates for admission as Associates must be persons not under twenty-five years of age, who from their scientific attainments or position in society may be considered eligible by the Council. They may afterwards be transferred at the discretion of the Council to the class of Associate Members or of Members.

5. The Council shall have the power to nominate as Honorary Life Members persons of eminent scientific acquirements, who in their opinion are eligible for that position.

6. The Members, Associate Members, Graduates, Associates, and Honorary Life Members shall have notice of and the privilege to attend all Meetings; but Members and Associate Members only shall be entitled to vote thereat.

7. The abbreviated distinctive Titles for indicating the connection with the Institution of Members, Associate Members, Graduates, Associates, or Honorary Life Members thereof, shall be the following:—for Members, M. I. Mech. E.; for Associate Members, A. M. I. Mech. E.; for Graduates, G. I. Mech. E.; for Associates, A. I. Mech. E.; for Honorary Life Members, Hon. M. I. Mech. E.

8. Subject to such regulations as the Council may from time to time prescribe, any Member, Associate Member, or Associate may upon application to the Secretary obtain a Certificate of his membership or other connection with the Institution. Every such certificate shall remain the property of, and shall on demand be returned to, the Institution.

ENTRANCE FEES AND SUBSCRIPTIONS.

9. Each Member shall pay an Annual Subscription of £3, and on election an Entrance Fee of £2.

10. Each Associate Member shall pay an Annual Subscription of £2 10*s*., and on election an Entrance Fee of £1. If afterwards transferred by the Council to the class of Members, he shall pay on transference 10*s*. additional subscription for the current year, and £1 additional entrance fee.

11. Each Graduate shall pay an Annual Subscription of £1 10*s*., but no Entrance Fee. Any Graduate elected prior to 1893, if transferred by the Council to the class of Associate Members, shall pay on transference £1 additional subscription for the current year, but no additional entrance fee; if transferred direct to the class of Members, he shall pay on transference £1 10*s*. additional subscription for the current year, and £1 additional entrance fee.

12. Each Associate shall pay an Annual Subscription of £2 10*s*., and on election an Entrance Fee of £1. If afterwards transferred by the Council to the class of Associate Members, he shall pay on transference no additional subscription or entrance fee. If transferred direct to the class of Members, he shall pay on transference 10*s*. additional subscription for the current year, and £1 additional entrance fee; except Associates elected prior to 1893, who shall pay no additional entrance fee on transference.

13. All subscriptions shall be payable in advance, and shall become due on the 1st day of January in each year; and the first subscription of Members, Associate Members, Graduates, and Associates, shall date from the 1st day of January in the year of their election.

14. In the case of Members, Associate Members, Graduates, or Associates, elected in the last three months of any year, the first subscription shall cover both the year of election and the succeeding year.

15. Any Member, Associate Member, or Associate, whose subscription is not in arrear, may at any time compound for his subscription for the current and all future years by the payment of Fifty Pounds, if paid in any one of the first five years of his membership. If paid subsequently, the sum of Fifty Pounds shall be reduced by One Pound per annum for every year of membership after five years. All compositions shall be deemed to be capital moneys of the Institution.

16. The Council may at their discretion reduce or remit the annual subscription, or the arrears of annual subscription, of any Member or Associate Member who shall have been a subscribing member of the Institution for twenty years, and shall have become unable to continue the annual subscription provided by these By-laws.

17. No Proceedings or Ballot Lists or Certificates shall be sent to Members, Associate Members, Graduates, or Associates, who are in

arrear with their subscriptions more than twelve months, and whose subscriptions have not been remitted by the Council as hereinbefore provided.

ELECTION OF MEMBERS, ASSOCIATE MEMBERS, GRADUATES, AND ASSOCIATES.

18. A recommendation for admission according to Form A or B in the Appendix shall be forwarded to the Secretary, and by him be laid before the next Meeting of the Council. The recommendation must be signed by not less than five Members or Associate Members if the application be for admission as a Member or Associate Member or Associate, and by three Members or Associate Members if it be for a Graduate.

19. All elections shall take place by ballot, four-fifths of the votes given being necessary for election.

20. All applications for admission shall be communicated by the Secretary to the Council for their approval previous to being inserted in the ballot list for election, and the approved ballot list shall be signed by the President and forwarded to the Members and Associate Members. The name of any Candidate approved by the Council for admission as an Associate Member or an Associate shall not be inserted in the ballot list until he has signed the Form C in the Appendix. The ballot list shall specify the name, occupation, and address of the Candidates, and also by whom proposed and seconded. The lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

21. The Elections shall take place at the General Meetings only.

22. When the proposed Candidate is elected, the Secretary shall give him notice thereof according to Form D; but his name shall not be added to the register of the Institution until he shall have paid his Entrance Fee and first Annual Subscription, and signed the Form E in the Appendix.

23. In case of non-election, no mention thereof shall be made in the Minutes, nor any notice given to the unsuccessful Candidate.

24. An Associate Member desirous of being transferred to the class of Members, or an Associate to the class of Associate Members or of Members, shall forward to the Secretary a recommendation according to Form F in the Appendix, signed by not less than five Members or Associate Members, which shall be laid before the next meeting of Council for their approval. On their approval being given, the Secretary shall notify the same to the Candidate according to Form G; but his name shall not be added to the list of Members or Associate Members until he shall have signed the Form H, and shall have paid the additional entrance fee (if any), and the additional subscription (if any) for the current year.

ELECTION OF PRESIDENT, VICE-PRESIDENTS, AND MEMBERS OF COUNCIL.

25. Candidates shall be put in nomination at the General Meeting preceding the Annual General Meeting, when the Council are to present a list of their retiring Members who offer themselves for re-election; any Member or Associate Member shall then be entitled to add to the list of Candidates. The ballot list of the proposed names shall be forwarded to the Members and Associate Members. The ballot lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

APPOINTMENT AND DUTIES OF OFFICERS.

26. The Treasurer shall be a Banker, and shall hold the uninvested funds of the Institution, except the moneys in the hands of the Secretary for current expenses. He shall be appointed by the Members and Associate Members at a General or Special Meeting, and shall hold office at the pleasure of the Council.

27. The Secretary of the Institution shall be appointed, as and when a vacancy occurs, by the Members and Associate Members at a General or Special Meeting, and shall be removable by the Council upon six months' notice from any day. The Secretary shall give the same notice. The Secretary shall devote the whole of his time to the work of the Institution, and shall not engage in any other business or profession.

28. It shall be the duty of the Secretary, under the direction of the Council, to conduct the correspondence of the Institution; to attend all meetings of the Institution, and of the Council, and of Committees; to take minutes of the proceedings of such meetings; to read the minutes of the preceding meetings, and all communications that he may be ordered to read; to superintend the publication of such papers as the Council may direct; to have the charge of the library; to direct the collection of the subscriptions, and the preparation of the account of expenditure of the funds; and to present all accounts to the Council for inspection and approval. He shall also engage (subject to the approval of the Council) and be responsible for all persons employed under him, and set them their portions of work and duties. He shall conduct the ordinary business of the Institution, in accordance with the Articles and By-laws and the directions of the President and Council; and shall refer to the President in any matters of difficulty or importance, requiring immediate decision.

MISCELLANEOUS.

29. All Papers shall be submitted to the Council for approval, and after their approval shall be read by the Secretary at the General Meetings, or by the Author with the consent of the Council; or, if so directed by the Council, shall be printed in the Proceedings without having been read at a General Meeting.

30. All books, drawings, communications, &c., shall be accessible to the members of the Institution at all reasonable times.

31. All communications to the Meetings shall be the property of the Institution, and be published only by the authority of the Council.

32. None of the property of the Institution—books, drawings, &c.—shall be taken out of the premises of the Institution without the consent of the Council.

33. All donations to the Institution shall be enumerated in the Annual Report of the Council presented to the Annual General Meeting.

34. The General Meetings shall be conducted as far as practicable in the following order:—

1st. The Chair to be taken at such hour as the Council may direct from time to time.

2nd. The Minutes of the previous Meeting to be read by the Secretary, and, after being approved as correct, to be signed by the Chairman.

3rd. The Ballot Lists, previously opened by the Council, to be presented to the Meeting, and the new Members, Associate Members, Graduates, and Associates elected to be announced.

4th. Papers approved by the Council to be read by the Secretary, or by the Author with the consent of the Council.

35. Each Member or Associate Member shall have the privilege of introducing one friend to any of the Meetings; but, during such portion of any meeting as may be devoted to any business connected with the management of the Institution, visitors shall be requested by the Chairman to withdraw, if any Member or Associate Member asks that this shall be done.

36. Every Member, Associate Member, Graduate, Associate, or Visitor, shall write his name and residence in a book to be kept for the purpose, on entering each Meeting.

37. The President shall ex officio be member of all Committees of Council.

38. Seven clear days' notice at least shall be given of every meeting of the Council. Such notice shall specify generally the business to be transacted by the meeting. No business involving the expenditure of the funds of the Institution (except by way of payment of current salaries and accounts) shall be transacted at any Council meeting unless specified in the notice convening the meeting.

39. The Council shall present the yearly accounts to the Annual General Meeting, after being audited by a professional accountant, who shall be appointed annually by the Members and Associate Members at a General or a Special Meeting, at a remuneration to be then fixed by the Members and Associate Members.

40. Any member wishing to have a copy of the Papers sent to him for consideration beforehand can do so by sending in his name once in each year to the Secretary; and a copy of all Papers shall then be forwarded to him as early as possible prior to the date of the Meeting at which they are intended to be read.

41. At any Meeting of the Institution any member shall be at liberty to re-open the discussion upon any Paper which has been read or discussed at the preceding Meeting; provided that he signifies his intention to the Secretary at least one month previously to the Meeting, and that the Council decide to include it in the notice of the Meeting as part of the business to be transacted.

APPENDIX.

FORM A.

Mr. being years of age, and desirous of admission into The Institution of Mechanical Engineers, we, the undersigned proposer and seconder from our personal knowledge, and the three other signers from trustworthy information, propose and recommend him as a proper person to belong to the Institution.

Witness our hands, this day of

Members or Associate Members.

FORM B.

Mr. born on being desirous of admission into The Institution of Mechanical Engineers, we, the undersigned proposer and seconder from our personal knowledge, and the other signer or signers from trustworthy information, propose and recommend him as a proper person to become a Graduate thereof.

Witness our hands, this day of

Members or Associate Members.

FORM C.

If elected an of The Institution of Mechanical Engineers, I, the undersigned, do hereby engage to ratify my election by signing the form of agreement (E) and paying the Entrance Fee and Annual Subscription in conformity with the By-laws.

Witness my hand, this day of

FORM D.

Sir,—I have to inform you that on the you were elected a of The Institution of Mechanical Engineers. For the ratification of your election in conformity with the rules, it is requisite that the enclosed form be returned to me with your signature, and that your Entrance Fee and first Annual Subscription be paid, the amounts of which are and respectively. If these be not received within two months from the present date, the election will become void.

I am, Sir, Your obedient servant,

Secretary.

FORM E.

I, the undersigned, being elected a of The Institution of Mechanical Engineers, do hereby agree that I will be governed by the regulations of the said Institution, as they are now formed or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of

FORM F.

Mr. being years of age, and desirous of being transferred into the class of of The Institution of Mechanical Engineers, we, the undersigned, from our personal knowledge recommend him as a proper person to be so transferred by the Council.

Witness our hands, this day of

Members or Associate Members.

FORM G.

Sir,—I have to inform you that the Council have approved of your being transferred to the class of of The Institution of Mechanical Engineers. For the ratification of your transference in conformity with the rules, it is requisite that the enclosed form be returned to me with your signature, and that your additional Entrance Fee and additional Annual Subscription for the current year be paid, the amounts of which are and respectively. If these be not received within two months from the present date, the transference will become void.

I am, Sir, Your obedient servant,

Secretary.

FORM H.

I, the undersigned, having been transferred to the class of of The Institution of Mechanical Engineers, do hereby agree that I will be governed by the regulations of the said Institution, as they now exist, or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of